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THE MAY SCIENTIFIC MONTHLY

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THE SCIENTIFIC MONTHLY

MAY, 1928

THE INFLUENCE OF BODILY LOCOMOTION IN SEPARATING MAN FROM THE MONKEYS AND APES

By Professor HENRY FAIRFIELD OSBORN

HONORARY CURATOR OF VERTEBRATE PALEONTOLOGY, AMERICAN MUSEUM OF NATURAL HISTORY

By far the most interesting problem in anthropology to-day is that of our Tertiary ancestors. Were they ape-men or Dawn Men? If we were to actually discover the complete skeleton of a pro-man in Lower Miocene or Oligocene time, would it be more like a man or more like an ape? The latter opinion is the widely prevailing one at the present time, and against it I raised, at the bicentenary meeting of the American Philosophical Society last April, what I call the Dawn Man theory, and I went so far as to stigmatize the ape-man theory as a myth.

Myth, derived from the Greek word muthos, signifying "legend," is defined[1] as "a legend; a traditional story, often founded on some fact of nature, or on an event in the early history of a people, and embodying some religious belief of that people." What I term the "ape-myth" rests upon no such slender evidence as a single fact in nature; it has grown up through more than a century of substantial observations in zoology and comparative anatomy; it is buttressed by recent discoveries in the development of the human brain, in the embryonic and foetal development of man, by many facts in the fossil history of man, and it is now supported by all the ablest and keenest students of human ancestry on the anatomical side—Sir Arthur Keith, Professor G. Elliot Smith, Professor William King Gregory, Professor J. Howard McGregor, Professor Frederick Tilney, Dr. Dudley J. Morton—also by many anatomists of a much more radical school, such as Dr. Hermann Klaatsch, who derives different races of man directly from different races of anthropoid apes.

Against such an array of profound and widespread research, as well as of character and sincerity, I feel like a youthful David stepping out to oppose a mighty Goliath. I admit that evidence on either side of this most interesting and friendly controversy is still not absolutely conclusive and that in the end Goliath may throw a stone more forceful than David's! In some fundamentalist quarters it is alleged that I have recanted the theory of the ascent of man from a much more primitive stage. This, of course, is the very reverse of my present Dawn Man theory of human ancestry, which may be expressed as follows:

Man sprang from partly tree-living (arboreal), partly ground-living (terrestrial) higher primates, of the kind known as "anthropoid" because of their nearer resemblance to man than to the

[1] The Winston Simplified Dictionary, 1926.

FIG. 1. THE LONG, SLENDER FINGERS OF THE GIBBON ADAPTED TO HYPER-ARBOREAL, BRACHIATING LIFE. SCENE FROM "CHANG," A PARAMOUNT PHOTOPLAY.

monkeys, baboons and lemurs. The fingers of the ancestral hand were broad and separated, the thumb well developed, with grasping power; the toes of the ancestral foot, on the contrary, were brought together, and the big toe was slightly separated. Thus in both the hand and foot these pro-human anthropoids were adapted both to tree and to ground progression. Neither hand nor foot was so far specialized for extreme arboreal life as to be disabled for an early tool-making power of the hand and for a nearly bipedal and cursorial power of the limbs and feet. Similarly, the pro-human brain conserved the alertness of all smaller primates in the terrestrio-arboreal stage but retained the potentiality of directing separate motions of the fingers and thumb in shaping defensive and offensive weapons, and the potentiality of directing rapid motions of the limbs and feet in bipedal, cursorial life, defensive and offensive.

This theoretic picture of *adaptation to habit* in our Dawn Man and pro-Dawn Man ancestors is, in my opinion, largely sustained by the embryonic, the foetal and the adult structure of the human hand and foot. These prenatal locomotor organs afford evidence of arboreal adaptation *far antecedent to the highly specialized brachiating or limb-swinging hand and limb-grasping foot of the anthropoid apes.* In other words, according to the Dawn Man theory the human family branch scientifically known as the *Hominidae* has since Lower Miocene and perhaps Upper Oligocene time been independent from the ape branch known as the *Simiidae* or snub-nosed primates. The innumerable resemblances between apes and man in functional, anatomical, psychical and physiognomic characters

are, by the Dawn Man theory, interpreted partly as parallelisms or convergences and partly as heritages from a common stock technically known as the primate Order *Anthropoidea*.

Origin of the Ape-man Myth

Children, behold the Chimpanzee:
He sits on the ancestral tree
From which we sprang in ages gone.
I'm glad we sprang: had we held on,
We might, for aught that I can say,
Be horrid Chimpanzees to-day.
—Oliver Herford.[2]

The ape-man myth has a long prehistory. The natives of the East Indies who observed the gibbon and the orang and the natives of Africa who observed the chimpanzee and the gorilla independently assigned human names to these anthropoid apes. Early naturalists, such as De Bry (1598), Hoppius, a pupil of Linnaeus, Tyson (1699), represented the apes as walking erect, and they supplemented the accounts of explorers by exaggerating human resemblances. The strong resemblances of the apes to man was cited by Buffon in a veiled suggestion of relationship. Lamarck went further and said that in the evolution of man from the ape the erect position was necessary to free the hand. Du Chaillu was forced by his publishers to exaggerate human characteristics of the gorilla, and the French sculptor Fremiet put into bronze the mythical stories of the gorilla in erect attitude closely resembling man. Recently Carl E. Akeley demonstrated the true locomotor habits —on all fours—of this giant ape, confirming the accurate observations of several naturalists. Haeckel, like other early disciples of Darwin, grossly exaggerated the ape-human resemblances in his "Anthropogenie" by placing ape skeletons all alike in a false erect position, while Huxley in his masterly "Man's Place in Nature" contended,

[2] "The Poetry Cure," by Robert Haven Schauffler, p. 54.

Fig. 2. The hooked hands (angulodactyly), elongated arms, short legs, spreading big toe of the black Gibbon. Courtesy New York Zoological Park.

against his great opponent Owen, for the close kinship of the apes to man.

Origin of the Ape-man Theory

Beginning with Darwin in 1874, there has been a continuous and more or less theoretic discussion, first as to the kinship of man to various lower primates, second as to the point in the lower primate scale from which the human family was given off. Darwin's opinions are clearly set forth in the following citations:

As we have no record of the lines of descent, the pedigree can be discovered only by observ-

the Gorgon's spell; petrify.
or″gon-zo′la, 1 gôr″gon-zō′lə; 2 gŏr″gŏn-zō′la, *n.* A cheese of pressed milk made at Gorgonzola, Italy.
;o-ril′la, 1 go-ril′ə; 2 gŏ-ril′a, *n.* A manlike and ferocious African ape about five and a half feet in height, with a massive body and limbs. [< Gr. *gorilla.*]
;or′ki, 1 gôr′kɪ; 2 gôr′ki, **Maxim.** See PYESHKOV.
;or′mand, } 1 gō r′[*or* **;our′mand,** } gūr′]mənd; 2 gôr′[*or* gur′]mand, *n.* **1.** A glutton. **2.** An epicure; gourmet. [< F. *gourmand,* glutton.] — **gor′mand-ize,** *vi. & vt.* [-IZED; -IZ″ING.] To eat voraciously. **gor′-mand-ise†.** — **gor′mand-iz″er** or **-is″er,** *n.*

Gorilla.
1/37

FIG. 3. THE GORILLA AS DEFINED AND PICTURED IN FUNK AND WAGNALLS'S DESK STANDARD DICTIONARY (1917).

ing the degrees of resemblance between the beings which are to be classed. (1874, p. 199.)

If man had not been his own classifier, he would never have thought of founding a separate order for his own reception. (1874, p. 201.)

There can, consequently, hardly be a doubt that man is an offshoot from the Old World Simian stem; and that under a genealogical point of view, he must be classed with the Catarrhine division. (1874, p. 206.)

If the anthropomorphous apes be admitted to form a natural subgroup, then as man agrees with them not only in all those characters which he possesses in common with the whole Catarrhine group, but in other peculiar characters . . . we may infer that some ancient member of the anthropomorphous subgroup gave birth to man. (1874, p. 206.)

But a naturalist would undoubtedly have ranked as an ape or a monkey an ancient form which possessed many characters common to the Catarrhine and Platyrrhine monkeys, other characters in an intermediate condition, and some few, perhaps, distinct from those now found in either group. And as man from a genealogical point of view belongs to the Catarrhine or Old World stock, we must conclude, however much the conclusion may revolt our pride, that our early progenitors would have been thus properly designated [namely, as monkeys]. (1874, p. 207.)

It is therefore probable that Africa was formerly inhabited by extinct apes closely allied to the gorilla and chimpanzee; and as these two species are now man's nearest allies, it is somewhat more probable that our early progenitors lived on the African continent than elsewhere. (1874, p. 208.)

The Simiidae then branched off into two great stems, the New World and Old World monkeys; and from the latter, at a remote period, Man, the wonder and glory of the Universe, proceeded. (1874, p. 221.)

The foot was then prehensile, judging from the condition of the great toe in the foetus; and our progenitors, no doubt, were arboreal in their habits. (1874, p. 215.)

Nearly all the other and more important differences between man and the Quadrumana are manifestly adaptive in their nature, and relate chiefly to the erect position of man; such as the structure of his hand, foot and pelvis, the curvature of his spine and the position of his head. The family of seals offers a good illustration of the small importance of adaptive characters for classification. These animals differ from all the other Carnivora in the form of their bodies and in the structure of their limbs, far more than does man from the higher apes; yet in most systems, from that of Cuvier to the most recent one by Mr. Flower, seals are ranked as a mere family in the Order of Carnivora. (1874, p. 200.)

From what we see going on under domestication, we learn that some of the co-descendants of the same species may be not at all, some a little, and some greatly changed, all within the same period. Thus it may have been with man, who has undergone a great amount of modifica-

tion in certain characters in comparison with the higher apes. (1874, p. 209.)

The recent views of William King Gregory, as fully detailed in his successive masterly papers since 1916 ("Notharctus Memoir," "Our Face from Fish to Man," etc.), have been summarized by him (1928) as follows:

An impartial reading of the 1916 paper will show a surprising agreement in general viewpoint with Darwin's, although it was written entirely independently and I regret to say with all too scant knowledge of Darwin's writings. Since 1916, in many papers, I have defended the view that man is an offshoot of some early member of the anthropoid stock, more or less nearly related to some of the wide-ranging dryopithecoid group and that his nearest existing relatives are the chimpanzee and the gorilla. I prefer not to quibble about whether the long-snouted, long-tailed, tree-living primate with grasping hands and feet, assumed as man's very remote ancestor, should be called by some less pleasant name than monkey.

In many papers since 1916 I have cited evidence tending to show that however long the final plains-living, cursorial stage may have lasted, it was immediately preceded by an arboreal primitive anthropoid stage with a gorilloid type of foot.

The stage preceding the terrestrial, cursorial biped has, to my mind, always been a brachiating pro-anthropoid, nearer on the whole to the chimpanzee than to Homo sapiens but without the extreme arboreal specializations of the orang.

The last paragraph is italicized because it contains the gist of Gregory's present theory. Sir Arthur Keith, following his studies on all the previous literature, including Gregory's researches,

FIG. 4. THE ARBOREAL, LIMB-SWINGING, BRACHIATING ORANG, WITH HOOKED FINGERS, ABBREVIATED THUMB, SPREADING BIG TOE. COURTESY NEW YORK ZOOLOGICAL PARK.

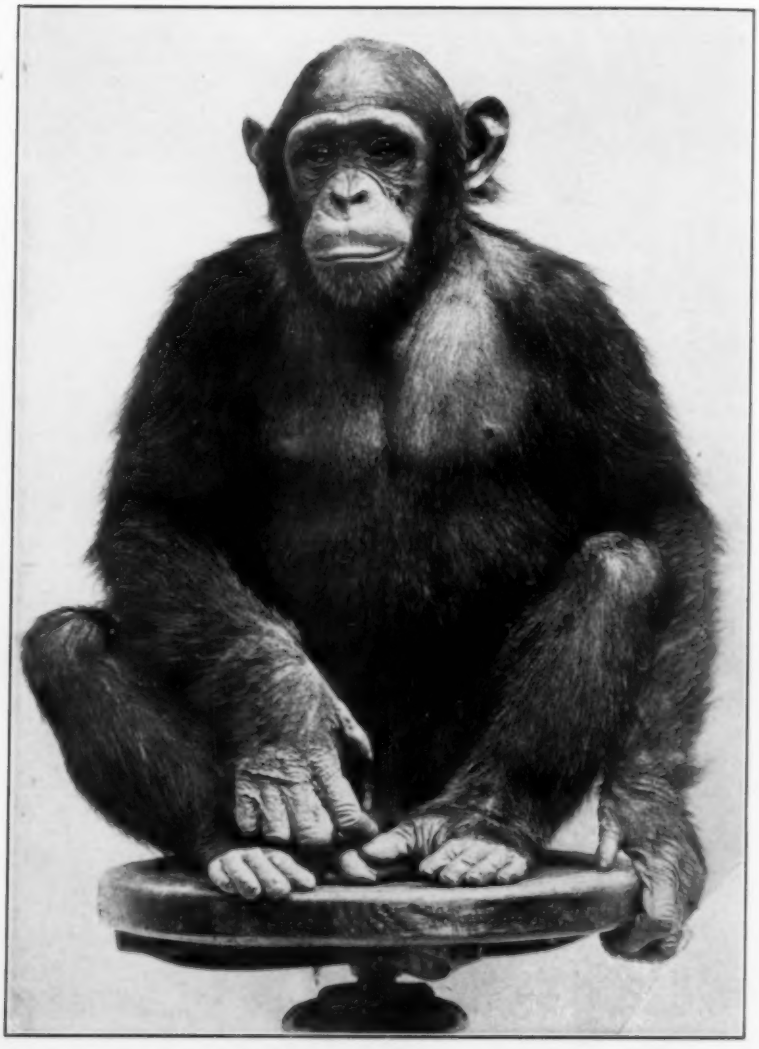


FIG. 5. THE SECONDARY ARBOREO-TERRESTRIAL CHIMPANZEE, WITH POWERFUL HOOKED FINGERS (ANGULODACTYLY), GREATLY ABBREVIATED THUMB, ENLARGED BIG TOE. FULLY ADULT STAGE. COURTESY NEW YORK ZOOLOGICAL PARK.

in his notable address[3] before the British Association, concludes:

> No one can compare the teeth of the(se) Miocene anthropoids with those of primitive man, as has been done so thoroughly by Dr. William King Gregory, and escape the conviction that in the dentitions of the extinct anthropoids of the Miocene jungles we have the ancestral forms of human teeth.
>
> It is useless to go to strata still older than the Miocene in search of man's emergence; in such strata we have found only fossil traces of emerging anthropoids. All the evidence now at our disposal supports the conclusion that man has arisen, as Lamarck and Darwin suspected, from an anthropoid ape not higher in the zoological scale than a chimpanzee, and that the date at which human and anthropoid lines of descent began to diverge lies near the

[3] Sir Arthur Keith: "Darwin's Theory of Man's Descent as it Stands To-day." Presidential address to the British Association, Leeds, England, August 31, 1927.

beginning of the Miocene period. On our modest scale of reckoning, that gives man the respectable antiquity of about one million years.

Thus the highest British authority (Keith) and the highest American authority (Gregory) of the present time agree not only as to man's strong kinship to the apes but as to man's descent from a primitive ape-like form more closely resembling the chimpanzee than man but less specialized in ape-like habits than the orang.

When we concentrate our attention on the form and functions of the hand and foot, on the relative proportions of the limbs, on the age-long effects of the bipedal cursorial habit of our own ancestors in contrast with the quadrumanal arboreal brachiating habit of the ancestors of the anthropoid apes, I reach widely different conclusions from my colleagues as to the relationship of man to the apes.

Proof of Man's Kinship to the Apes

All pioneers in this most interesting discussion have naturally tended to dwell upon the resemblances in the brain and other organs rather than to summarize the profound differences in the entire locomotor organization.

Gregory (November 18, 1927) has compiled tables (not yet published) which he entitles "Significant Marks

Fig. 6. The walking, juvenile Chimpanzee, balanced by the extended arms, with hooked fingers (angulodactyly), shortened legs. The arm stretch is less extreme than in the Orang and much less extreme than in the Gibbon. Courtesy New York Zoological Park.

FIG. 7. THE KNUCKLE-WALKING, QUADRUMANAL GAIT OF THE GORILLA, "DINAH," DUE TO THE PRONOUNCED ANGULODACTYLY. THE PROLONGED LIMB-SWINGING USE OF THE FINGERS PREVENTS THE OPENING OF THE HAND AND ENFORCES THIS KNUCKLE-WALKING PROGRESSION. COURTESY NEW YORK ZOOLOGICAL SOCIETY.

of Man's Kinship to the Anthropoid Apes." These tables are checked to indicate (a) substantially identical conditions, (b) nearness to man, (c) marked resemblance or approach, (d) intermediate conditions, (e) radical differences or contrasts, (f) occurrence as variants, (g) occurrence as vestiges, (h) normal condition. Summarizing the recent work of Tilney, Schultz, Straus, Keith, Landsteiner, Woolard and others, and the earlier work of Retzius, Hubrecht, Sonntag, McGregor, Selenka, Deniker, Pocock, Bolk, Reichenow, Huntington, Todd, Willis, Boas, etc., the conclusion is reached that "the evidence for man's kinship with the anthropoids and for arboreal derivation is now overwhelming," especially in the following characters: (1) general physiology: blood and chemical reactions, susceptibility to characteristically human diseases; (2) reproduction and development, all phenomena; (3) fundamental habits of social and family life; (4) in another class of characters, namely, the trunk and vertebral column, the fundamental relations of the limb arches to the trunk, such as the loss of the caudal vertebrae (tail), change of function in the tail muscle, shortening of the lumbar region, foetal proportions of the limbs and innumerable other foetal characters, the kinship is equally strong. The above physiological and organic differences are in large measure supported by adult axial and by foetal limb stages. (5) There are marked resemblances in the lips, mouth and throat, in the structure of the tongue, mouth glands and larynx, and (6) in the endocrine system, in the sense organs, the accessory points of hearing, in the eyes and vision, there is striking likeness between man and the anthropoid apes, as especially developed by the brain studies of Elliot Smith and

FIG. 8. THE SOLE OF THE FOOT OF THE GORILLA, "DINAH," SHOWING THE GREATLY ENLARGED AND SPREADING BIG TOE AND THE RELATIVELY SHORT, APPRESSED TOES. COMPARE WITH THE FOETAL HUMAN FEET (FIGS. 9, 10) AND NOTE GENERAL RESEMBLANCE. COURTESY NEW YORK ZOOLOGICAL SOCIETY.

of Tilney. (7) In brain and mentality, from the time of Flechsig, the strong points of superficial cerebral resemblance of the ape to man have been increasingly observed and have recently been extended in Tilney's studies of the central brain structure and tested by the remarkable psychiatry of Yerkes.

It will be observed by careful study of Gregory's kinship tables that *the majority of characters which establish the kinship of the anthropoid apes to man are primitive characters also possessed by a long remote, common anthropoid stem.* They subserve functions of reproduction, of the sense organs, of social and family relationship, of the central part of the skeleton, which are equally serviceable to anthropoid primates which may differ widely in locomotor structure and habit.

Let us therefore reexamine the anthropoid apes from the standpoint of bodily locomotion in its direct bearing upon life habits and upon all the psychic actions and reactions of the limbs, feet and hands, especially of the hands.

Influence of Bodily Locomotion

As to which anthropoid comes nearest to man Gregory's generalization from the hundreds of descent observations is as follows, in descending order:

Modernized man
Primitive man
Chimpanzee of the African forests
Gorilla of the African forests
Orang of the East Indies
Gibbon of the East Indies
Old World monkeys
New World monkeys
Tarsius
(Lemuroids, lemurs)

The known phylogenetic or ancestral relationships to each other of these various branches of the great order of Primates is shown in a chart after Gregory.

Habit is king, because function rules the locomotor organs and ultimately determines their structure, whereas the organs merely condition and limit the functions. We now enter an entirely new field of human or ape progress, which Gulick (1905) terms "habitudinal evolution." Such evolution in the locomotor organs results in what Gregory has aptly termed "habitus," or external form and appearance of relatively recent acquisition in contrast to the "heritage" of more profound and less conspicuous characters of remote, common ancestral origin.

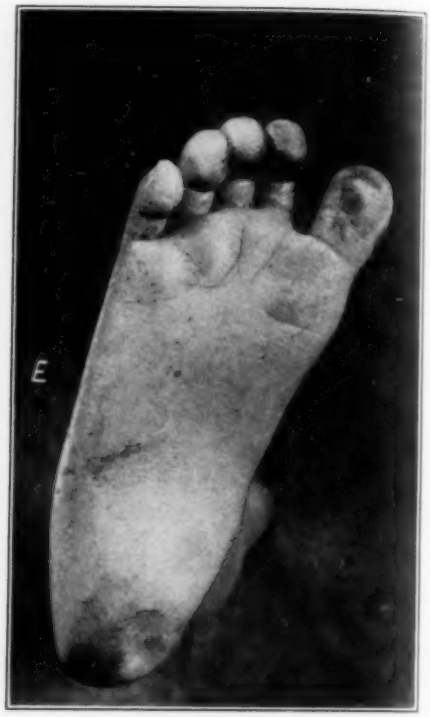
But the general adjectives "arboreal," "terrestrial" and "cursorial" do not fully classify or subdivide the *phases* of habit, of ground or of tree life. Analysis of foot and hand structure reveals the following kinds of primary and secondary adaptations:

(1) Terrestrial insectivorous and carnivorous animals which seek or chase their prey in trees (*e.g.*, tree shrews, leopard, panther)
(2) Terrestrial herbivorous animals which seek food in trees (*e.g.*, squirrels)
(3) Terrestrial animals which seek defense in trees, ending in home building (*e.g.*, orang)

These habits result in the following progressive arboreal stages:

(a) Terrestrio-arboreal, carnivorous, insectivorous, herbivorous mammals
(b) Arboreo-limb-walking, *e.g.*, squirrels
(c) Arboreo-volant, *e.g.*, flying squirrel
(d) Arboreo-limb-swinging and brachiating, *e.g.*, chimpanzee, orang
(e) Hyper-arboreo-brachiating, *e.g.*, gibbon, tree-sloth
(f) Secondary arboreo-terrestrial, *e.g.*, chimpanzee, orang
(g) Secondary terrestrio-arboreal, *e.g.*, gorilla.

Recent man, as well as Stone Age man, including the now well-known Cro-Magnon, Neanderthal, Heidelberg, Trinil and Piltdown types, does not exhibit in limb structure or in hand and foot structure, so far as known, any of the essential arboreal adaptations, but on the hypothesis that man is descended from a tree-living ape type, embryonic and foetal reminiscences of former arboreal life should be apparent. The



FIGS. 9, 10. TWO STAGES IN THE DEVELOPMENT OF THE HUMAN FOETAL FOOT, SHOWING THE RELATIVELY ABBREVIATED AND WIDELY SPREADING BIG TOE. NOTE THE APPRESSED SMALLER TOES AS IN THE GORILLA. COMPARE FIG. 8. AFTER SCHULTZ.

most important effect of arboreal or of cursorial habit is shown in limb proportions, in the relative length of the arm and of the limb. But limb proportions differ widely in various arboreal types, as demonstrated by Morton[4] in his table of ratios. These ratios are discussed by Gregory[5] as follows:

ARM AND LEG LENGTH INDICES IN APES AND MAN

The contrast between the hyper-arboreal [ape] and the hyper-cursorial [man] types is beautifully illustrated in Dr. Schultz's drawing in which the fetal and adult stages of anthropoids and man are contrasted. This diagram is at the beginning of his paper on "Fetal Growth of Man and Other Primates."

[4] Dudley J. Morton: "Human Origin." *American Journal of Physical Anthropology*, Vol. X, No. 2, April–June, 1927, pp. 173–203.

[5] William King Gregory, letter to author, November 23, 1927.

(1) Arm length from head of humerus to ball of hand, in relation to length of trunk.

No recorded measurements are available giving the length of the arm extending only to the ball of the hand (as in the quadrumanal gait of the monkey), but a brief table (after Morton) shows the total length of the forearm in terms of sitting height. If the length of the torso (first dorsal vertebra to posterior end of ischium) is taken as unity, the combined length of the humerus and ulna is as follows:

In typical cursorial mammals (*e.g.*, dog)	40–46
In *Notharctus* (Eocene lemur)	49
In Lemuroids	60
In Old World monkeys	68
In Man	90
In Chimpanzee	97–100
In Gorilla	100
In Orang	118
In Gibbon	149

(2) Leg length from head of femur to ball of heel, in relation to trunk.

This measurement can not be given exactly because the head of the femur is not available for measurement in living animals, but close approximation to what is desired can be made by giving the total hind limb length (to great trochanter) in terms of sitting height.

In 1916 ("Evolution of the Primates," pp. 332, 335), I [Gregory] pointed out that such contrasts in indices are apt to be deceptive if they exhibit only the divergent end forms and lack the stem form from which both originated. In this case it seems probable that from the evidence of the brain and many other organs, the chimpanzee stands nearer to the stem forms than does the orang at one extreme or man at the other. The gibbon plainly is an offshoot of an earlier stage. This is well indicated in Schultz's diagrams. Doubtless in all such cases the critical question is not how much do the extremes differ but to what extent have both relative lengths and breadths been made over after a profound change of habits, such as the transition from the erectly-moving, arboreal, primitive brachiating stage to the hyper-brachiating stage (orang) on the one hand and to the long-legged, short-armed hyper-cursorial stage on the other.

The following indices were kindly collected by Dr. H. L. Shapiro, of the American Museum staff (letter to author, November 2, 1927):

(1) Arm (without hand) Relative to Length of Trunk

	Subjects exam.	Ratio
Man (Baden)	100	115.9
Neanderthal	1	115.4 (skeletal measures)
Chimpanzee	8	122.6
Gorilla	2	133.5
Orang-utan	5	160.2
Gibbon	29	188.8

Lower Arm Relative to Trunk

Man (Baden)	100	50.9
Chimpanzee	8	59.1
Gorilla	2	60.5
Orang-utan	5	78.4
Gibbon	29	97.8

Total Arm Length Relative to Trunk

Man (Baden)	152.7
Chimpanzee	180.1
Gorilla	188.5
Orang-utan	223.6
Gibbon	246.9

(2) Leg (without foot) Relative to Trunk

Man (Baden)	100	158.5
Neanderthal		158.6 (skeletal)
Chimpanzee	8	113.2
Gorilla	2	113.0
Orang	5	111.2
Gibbon	28	130.7

From these indices, derived differently from Morton's, I reach the following conclusions:

In both recent and Neanderthal man the measurement from the arm to the wrist or palm is 115 per cent. of the trunk measurement, whereas the hyper-arboreal arm of the gibbon is 188 per cent. of the trunk measurement. Similarly, the total arm length in man is 152 per cent. of the trunk measurement, while it rises to 180 per cent. in the chimpanzee and 246 per cent. in the gibbon. The comparative leg indices are just the opposite: both in recent and in Neanderthal man the leg is 158 per cent. of the trunk, while in the orang the length is 111 per cent. of the trunk. The adaptive principle in these

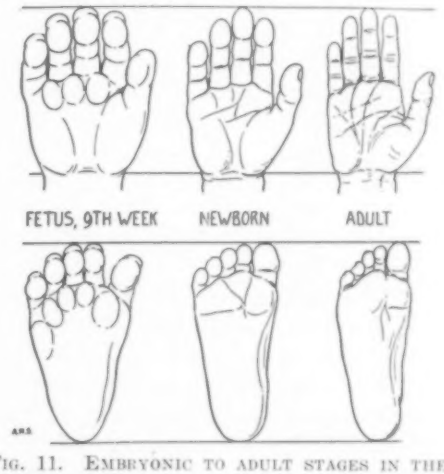


Fig. 11. Embryonic to adult stages in the human hand (upper row) contrasted with embryonic to adult stages in the human foot (lower row). After Schultz. Observe that in the foetus of the ninth week there is no trace of the slender or hook-like fingers of the anthropoid ape. Compare Fig. 12.

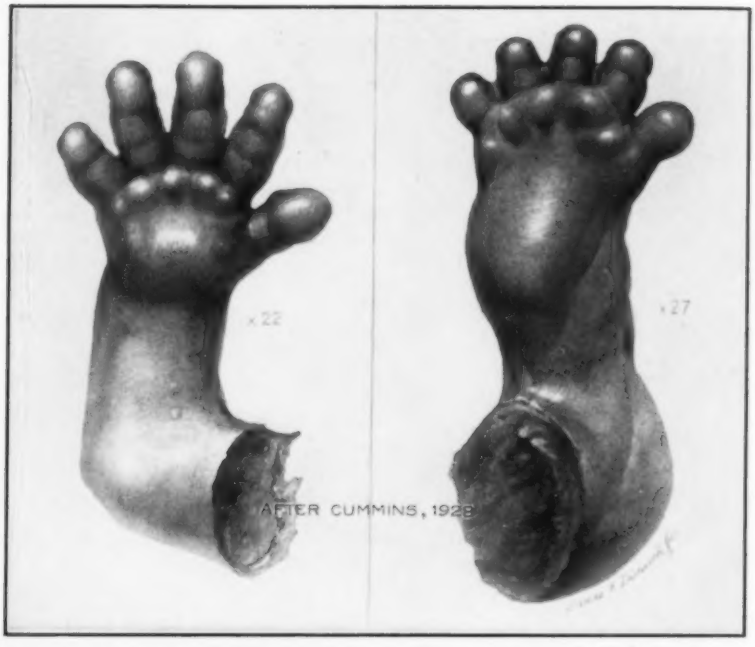


FIG. 12. EARLIEST SPREADING STAGE OF THE EMBRYONIC HUMAN HAND (LEFT) AND FOOT (RIGHT), GREATLY ENLARGED. AFTER SCHULTZ AND CUMMINS. OBSERVE THE WIDELY SPREADING FINGERS AND TOES AND THE ABSENCE OF ANY TRACE OF ANTHROPOID APE AFFINITY.

limb proportions is that as we ascend from the quadrumanal through the bipedal to the arboreal types of primates *the arms progressively lengthen and the legs retrogressively shorten;* on the contrary, when we descend from the arboreal through the quadrumanal to the cursorial type *the arms progressively shorten and the legs progressively lengthen.*

In the developing human infant, as clearly shown in the recent diagram of Schultz, the arms progressively shorten and the legs progressively lengthen. The human infant, therefore, in its early foetal stages has long arms and short legs, whereas in its late stages before birth it has arms and legs of nearly equal length. In this important respect the developing human being sustains the arboreal theory of human descent. In one of Schultz's valuable figures, however, it will be observed that the hands and fingers have been unintentionally elongated by the draughtsman, since the hand and fingers differ widely from the proportions shown in Fig. 11 (hand of the foetus of ninth week).

The developing human hand as illustrated by Retzius and more recently by Schultz does not appear to lend any support to the ape theory of human descent. From the earliest stages observed, the fingers are short and spreading, and at no stage do they give any evidence of the elongated hook-like form characteristic of all the anthropoid apes. They develop gradually in length and spread apart in preparation for their use in the crawling position of infancy, with relatively short, spreading fingers, rather than for the limb-swinging or brachiating function with closely appressed and elongated fingers. No one watching the marvelous flexibility and

the lightning-like innervation of the fingers of a great pianist like Paderewski or Horowitz, in which each finger and each joint move independently of every other, can conceive of the descent of the wonderful adult human hand from the brachiating type of the ape. It is rather derivable from the limb- or branch-walking and clinging type of hand of certain of the monkeys and lemurs.

Intensive Observations on the Limbs, Hands and Feet of Monkeys and Apes

With the rich resources in living primates of the New York Zoological Park Curator Raymond L. Ditmars, aided by Elwin R. Sanborn, has been photographing and closely observing the uses of the hand and foot in lemurs, monkeys and apes. The types especially examined are:

Lemurs
Slow lemur of India
Black and white lemur of Madagascar
Rhesus Monkey of India
Japanese Macaque
Pompadour Macaque of India
Potto of Africa.
Collared Mangabey of West Africa
DeBrazza Guenon of the Congo
Whitefaced Sapajou of South America
"Woolly Monkey," Lagothrix, of Brazil.
Woolly Monkey of Guiana
Saki Monkey of northern South America
Black Spider Monkey

These animals present all the phases of arboreal habit, from the slow-moving lemur and potto, which progress chiefly along the limbs and branches of trees, to the highly specialized and brachiating "spider monkeys," which parallel the gibbon in the power of rapid progression among the treetops. The limb indices and ratios of these animals have not been taken, but they indicate this progression to arboreal adaptation:

(a) Balanced length of fore and hind limbs
(b) Steady elongation of the fore limbs
(c) Static condition or reduction of the hind limbs
(d) Early limb-grasping power of the thumb (*e.g.*, Potto, Lagothrix, woolly monkey) sometimes retained
(e) Progressive reduction of the thumb (Ateles)
(f) Early limb-grasping power of the big toe (not elongated, *e.g.*, Potto)
(g) Big toe elongated and set apart (woolly monkey of the Guianas)
(h) Progressive elongation and syndactyly of the digits both of the hands and of the feet (spider monkeys).

Among the arboreal lemurs and monkeys of the Old World (Catarrhines) and of the New World (Platyrrhines) there is a great diversity in limb, hand and foot, owing partly to the survival of primitive limb-walking forms.

In the anthropoid apes *there is a strikingly uniform evolution into the highly specialized arboreal type known as limb-swinging or brachiating, invariably adaptive as follows:*

(a) Fore limb elongated in direct ratio to acquisition of hyper-arboreal habit
(b) Hind limb reduced in the same ratio
(c) Four digits of the hand directly elongated, appressed, with conjoined movement, *i.e.*, syndactyly
(d) Thumb actually and relatively abbreviated, with loss of grasping function
(e) Consequent final transformation of the hand into a hook, *i.e.*, angulodactyly
(f) Transformation of the foot into a hand by moderate elongation of the four main digits, and strong separation, development and grasping power of the big toe.

Thus the anthropoid apes are no longer quadrumanous, because the hand is completely transformed by losing its handlike functions, while the foot loses its footlike functions and is transformed into a hand. This adaptation is in widest possible contrast to the adaptation in the Bimana (the term originally applied to the human division), in which the hand is transformed into a super-hand and the foot into a super-foot, splendidly adapted to very rapid plantigrade, cursorial locomotion.

Accepting Dollo's dictum that evolution is never reversed, that lost organs are never regained, we do not conceive it possible that the brachiating anthropoid could reverse the whole direction of its evolution, regain its lost powers and diminished organs and set out in an entirely new direction into the bimanous pro-Dawn Man type.

McGregor's Notes on Tree Shinning and Erect Attitude in Apes and Man

The distinctively human powers of locomotion, of dexterous use of the hand and thumb, of bipedal and erect attitude, flash out here and there among the anthropoids as *vestigial functions*. It appears that in previous papers I have made certain misstatements in this connection, which I can best correct by quoting directly from my colleague, J. Howard McGregor, who writes, January 3, 1928:

You speak[6] of man "shinning up the tree by embracing the trunk with his arms and shins. "No anthropoid ape," you say, "displays this power. . . . *The ape must rise into the tree, not by the trunk route, but by the branches.*"

I wish you could have seen John Daniel 2nd[7] three years ago when Miss Cunningham, Captain Penny and I took him in a taxicab to a park in Newark. There was a number of quite straight trees, I should say from nine to twelve inches in diameter and with no branches lower than nine or ten feet from the ground. I was very much interested to see him rush rapidly up the trunks of these trees, very much as a boy would have climbed them, though of course, his arms being longer and his legs shorter, the knees seemed to project less than in the case of a boy. He did not exactly embrace the trunk with his shins, but placed the soles of his feet against it—very much like the men in the photograph from Lang which you publish. He seemed to enjoy climbing these trunks; there were several varieties of trees and he ran from tree to tree, climbing in all a considerable number—I should say certainly six or eight, at least. He would rush up a trunk out onto the branches and there he would swing. I remember in one case he let go a branch with his hands and swung head downward by his feet. On one occasion he hung from a branch with his hands and dropped to the ground as the small branch swung rather low.

Mr. Raven of the Museum tells me he has also seen *monkeys* in the East Indies climbing the smooth boles of trees very much as a man would climb.

[6] "Man Rises to Parnassus," p. 180; fig. 82.

[7] Young gorilla trained by Miss Alyse Cunningham.

Erect Attitude

I somehow gained the idea that you had stated that the earlier observers of the gorilla believed that it walked erect like a man, and that you gave Akeley some of the credit for disproving this. I have just been going over Du Chaillu's work and find him most emphatic in stating that the gorilla goes habitually on all fours, rising on the hind legs when he attacks—which would be quite necessary as the arms are used as weapons. I think the rather prevalent idea that the gorilla habitually walks like a man is simply a popular notion—probably based on nothing more substantial than the illustrations in Du Chaillu's work, all of which show the animal at the time of attack. The statement is made in Richard Owen's earliest papers on the gorilla that it goes on all fours. This is probably based on Savage's descriptions. On looking up Savage and Wyman's article published in the *Boston Journal of Natural History*, 1847, I find it says of the gorilla (page 423):

"The gait is shuffling; the motion of the body, which is never upright as in man, is somewhat rolling or from side to side. The arms being longer than the chimpanzee, it does not stoop as much in walking. Like that animal it makes progress by thrusting its arms forward, resting the hands on the ground and then giving the body a half-jumping, half-swinging motion between them. In this act it is said not to flex the fingers, as does the chimpanzee resting on the knuckles, but to extend them thus making a fulcrum of the hand. [This last statement is of course an error.—McG.] When it assumes the walking position, to which it is said to be much inclined, it balances its huge body by flexing the arms upward."

In my observations on John Daniel 2nd, I noticed that he very frequently rose to his hind legs, often taking a few steps in this position; and of course in beating his chest he always stood fairly erect on his hind feet. It was noticeable that sometimes when in a hurry he moved the arm and leg of the same side together, like the racking or pacing gait of a horse. This was by no means his habitual gait.

but I recall noticing and commenting on it. He also tended to keep one side in advance so that he seemed to run sideways. Miss Cunningham (or it may have been her nephew) told me that John Daniel 1st also had this oblique method of running.

I have just returned from a week in Sarasota, Florida, where, with Yerkes, I spent a great deal of time examining and photographing the female mountain gorilla "Congo." I noticed her gait with special care, and in no case did I observe this pacing gait. One hand and the opposite foot were always advanced at the same time, so I am inclined to think that the occasional pacing gait which I observed in John Daniel 2nd is not common. I had not observed it in either of two very young male gorillas which I have seen recently. These were babies approximately one year old. I may add that, on one occasion, I saw "Congo" rise to her hind feet and walk in erect position a distance of about ten or twelve feet to the opposite side of her large outdoor cage. I was fortunate in securing a number of photographs and also 16 mm. moving picture film of the gorilla in Florida.

Reduction of Thumb

I also feel that you rather exaggerate the reduction of the thumb in the anthropoid apes. Of course it is somewhat smaller than in man, but seems relatively smaller than it is because of the great elongation of the palm and fingers in the anthropoids. In some of the South American monkeys, even completely *arboreal* types such as *Lagothrix* (the woolly monkey of the forests of Brazil), the thumb, though not opposable, is quite as long as in man. This seems rather strange, because in *Ateles*—the spider monkey—which is undoubtedly very close to *Lagothrix*, the thumb reaches its maximum reduction. You state[8]: "All arboreal mammals are practically thumbless." Perhaps you mean *opposable* thumbs, but many Old World *monkeys* can perfectly oppose the tip of the thumb and the tip of the index finger. I have made numerous observations on these points. I hope soon to have motion picture films to illustrate the anthropoid method of climbing trees, and also the use of the thumb. I have a film (from Ditmars) showing a young chimpanzee using needle and thread, holding the needle as mentioned above.

[8] "Man Rises to Parnassus," p. 180.

Conclusion

This concludes our present survey of the influences of bodily locomotion in separating man from the monkeys and apes. It is clear, in so far as the evidence in this connection is concerned, that the theory of arboreal ancestry of the human type is well established, both by the proportions of the limbs and possibly by the inturning of the soles of the feet, also to a less degree by the spread of the big toe. It is possible that the intra-uterine abbreviation of the hind limb and even the inturned soles of the infant feet are an adaptation to the very confined position of the unborn infant.

On the other side of the case, the structure of the foetal and infant hand does not support the brachiating ape theory. The structure and proportions of the limbs, the hands and feet, taken altogether, do not harmonize with the brachiating ape theory, but, to my mind, suggest rather the taking off of the human stock from the second progressive arboreal stage, namely, arboreo-limb-walking stage (p. 393, b). Derived from this stage, the pro-Dawn Man would conserve all the potentiality of future application of the hand to flint-making and, ultimately, to the arts and industries by which man has arisen.[9]

[9] The sixth in a series of papers on human evolution, the preceding five having been presented as follows: (1) "Fundamental Discoveries of the Last Decade in Human Evolution," New York Academy of Medicine, April 7, 1927; (2) "Recent Discoveries Relating to the Origin and Antiquity of Man," American Philosophical Society, April 28, 1927; (3) "Recent Discoveries in Human Evolution," Medical Society of the County of Kings, May 17, 1927; (4) "Recent Discoveries Relating to the Origin and Antiquity of Man," *Palaeobiologica*, Band 1, December 7, 1927; (5) "The Influence of Habit in the Evolution of Man and the Great Apes," New York Academy of Medicine, December 16, 1927.

GROWING OLD AND THE SEARCH FOR AN ELIXIR OF LIFE[1]

By the late Professor A. C. EYCLESHYMER

In youth, the elastic, sturdy and vigorous body adapts itself most completely to its surroundings. We find, as Lubbock has said, that "every sort of beauty has been lavished on our allotted home; beauties to enrapture every sense, beauties to satisfy every taste; forms the noblest and loveliest, colors the most gorgeous and the most delicate; odors the sweetest and subtlest; harmonies the most soothing and the most stirring." The heart throbs, the senses quiver, and the brain overflows. We are in fullest appreciation of all nature.

As the years pass by, the body loses in elasticity, strength and vigor. The eye is not s okeen, nature's colors are not so bright; the ear is not so acute; we listen more intently to catch distant sounds; memory is not quite as reliable; reason not quite as trustworthy; the love of both work and pleasure is a little less; a few clouds appear on the horizon. We scarcely know that the summer of life is passing and that old age is approaching so quietly and gently.

The body becomes bent, rigid and fragile; the teeth decay, the hair falls out, the dried and wrinkled skin shows dark varicose veins; memory and reason are fast going; ambition and patience give way to despondency and irritability. The cold, dark clouds of life's winter are gathering; the ghastly image of old age is ever near and haunts us through the long restless nights. The scriptural formula "three score years and ten" makes the seventieth birthday for many persons the saddest of all.

[1] This manuscript left in incomplete form by Dr. Eyeleshymer on his death has been prepared for publication by his friend, Dr. E. P. Lyon.

As the great Hogarth's life was drawing to a close he painted a most remarkable picture. On the canvas he represented a broken bottle, a cracked bell, an unstrung bow, the signboard of a tavern called "The World's End" falling down, a shipwreck, the horses of Phoebus lying dead in the clouds, the moon in her last quarter, and the world on fire. "One thing more," said Hogarth, "and I am done"; he added to the picture a broken palette. It was his last work and it represented the last days of human life.

The human heart loves life in its fullness and yearns to prolong the period of youth. It recoils from the struggle with old age and ever tries to exclude the thought which brings but sorrow and pain. All the ideals, the dreams, the visions of immortality center around the conservation or restoration of an active body or mind, or both. No one has ever pictured the continuation of senile processes in the life beyond and through eternity.

The question of growing old is one of such moment that it has attracted thinkers of all ages. Patriarchs and prophets, philosophers and theologians, magicians and scientists have each tried to find some means of restoring youth or preventing old age.

Biblical narrative teaches us that there was a "tree of life" in the Garden of Eden. After Adam had eaten of the fruit of the "tree of knowledge," and thereby knew good and evil, the Lord sent him from the Garden "lest he put forth his hand and take also of the tree of life, and eat, and live forever." For centuries the idea prevailed that there must be, somewhere, a tree which was

intended by the Creator to preserve man from disease and death. The search for the tree of life was carried far and wide. Some thought it to be the aloe, others the cedar, still others the amber. The dark hellebore, the crocus and other herbs, their balsams and infusions also were thought to give new life.

The stars next attracted man. It was commonly believed, by the Egyptians and long after them, that the constellations and planets possessed either good or evil qualities which were given to those born under them. Astrology appealed not only to the ignorant but to the educated. Priests, poets, philosophers and physicians devoted much time to the casting of horoscopes. They could read in the heavens, so they thought, the day of birth, the peculiarities of life and the day of death. If it were possible to foretell the day of death, were it not possible to carry a life beyond the fixed date? This the astrologer attempted by locating the star causing the disease, and then invoking a beneficent star to annihilate the effects of the malignant one.

Since the metals were thought to be intimately associated with the planets, it was natural that the astrologers should advise the wearing of amulets or figures which had been cast, stamped and submitted to the influence of the stars, thereby imparting to the metal a subtle charm. Some talismans protected from fire, prison, wild beasts and the like; others were struck for the various diseases and finally, by adroitly mixing, talismans were cast which kept away all evil.

When astrology lost its influence over thinking people, through the discovery of the Copernican system and Newton's laws, alchemy became its successor.

Alchemy was based upon the assumption that somewhere among nature's hidden treasurers there was a substance which would produce gold from metals which contained no gold. The alchemists were not slow in realizing that so much gold would be of little value unless the life of man were long enough to spend it. Renewed efforts were made to find an elixir which would prevent disease, prolong life and restore youth. To what extent the Spagyric writers considered the philosopher's stone and the elixir of life identical is a question. By some, the elixir of life was said to be like sea-water; by others, like port or sherry wine; still others thought it to be an invigorating paste. By the greatest number it was thought to be liquid gold.

The sun, for ages, had poured its limpid golden rays upon the earth and had given to the earth power to bring back life. Each winter death fell upon the earth, but with the return of spring life came again. It was thought that the sun must be the source of life. Some went so far as to place open jars in the sunshine during the summer and then collected the dust in the autumn; this dust they regarded as the real solar powder which would give new life. Others thought that the sun's rays went deep into the earth, and when a careful search revealed mineral gold, it was believed to be the substance in which the life-giving rays were held fast.

As early as the eighth century, Gerber compounded a red elixir from gold, which he claimed would rejuvenate old people. The alchemists of the twelfth and thirteenth centuries became divided into schools, the one seeking to transmute the base metals to gold, the other trying to find that special potion which would cure all ills, preserve youth and prolong life.

The transmutation of metals later became the chief aim of alchemy, the love of life being gradually replaced by the love for gold. Moreover, it was easy to show an apparent transmutation of metals by clever tricks; but no deceit could show the return of youth in the aged.

The last serious attempt, on the part of the alchemists, to discover or compound an elixir of life was in the early part of the sixteenth century when a Swiss alchemist, commonly known as Paracelsus, who had studied deeply in chemistry, announced that "man is a chemical composition; disease causes an alteration in this composition; it thus is necessary to use chemical means to combat disease." Paracelsus thought that he had discovered how the vital spirit was formed and even went so far as to state that he could create men in an alembic. He burned the books of Galen and proclaimed that there was no disease he could not cure, nor life he could not prolong. So great became his notoriety that people flocked from all parts of the continent to be treated. It was later found that his "great elixir" or "vegetable sulphur," as it was called, was nothing more than a mixture of the extracts of aloe, myrrh and saffron.

In the days of the patriarchs, the idea arose that blood was the life fluid. Thus we read, in Deuteronomy, that flesh may be eaten but not blood. "Only be sure that thou eatest not the blood, for the blood is the life; and thou mayest not eat the life with the flesh." In ancient Rome, before the vast gathering in the Coliseum, the bleeding gladiator exclaimed: "Ave, Caesar, morituri te salutant!" As he thus saluted Nero, Roman women suffering from epilepsy rushed to the arena to drink the blood as it gushed from the fatal wounds. As time passed the blood was regarded by an increasing number as the life carrier, but the scriptural admonition kept man from using it to any extent until the time of Louis XI who, it is said, made real the fable of the vampire by frequently drinking the fresh blood of children as a means of rejuvenating himself.

About the middle of the seventeenth century, the art of transfusing blood arose. This was done by opening the vein of one animal and, by means of a tube, carrying over the blood into the vein of another animal. This was tried on horses and it was said that by transfusing the blood of a young horse into that of an old and decrepit one, the old horse became a colt again. It was also said that courage could be transfused into the timid by using the blood of the wild, and that the wild could be subdued by using the blood of the timid.

In 1667, Denys, of Paris, transfused about a pound of calf's blood into the veins of a maniac. This was twice repeated. The patient died and his wife brought suit against Denys. This resulted in transfusion being prevented by law, and for more than a hundred and fifty years this method was not practiced. When revived by Blundell, Diefenbach and Magendie, it was again fraught with dangers and was but little used.

Later, it was found that the blood of an animal undergoes dissolution when the blood of another species is transfused. The researches of Ehrlich and Morgenroth on haemolysis have given us a fairly clear understanding of this process.

Another supposed panacea, which must have been of very ancient origin, was based on the belief that the flesh of the serpent himself must be an antidote against his own death-dealing venom. In the early part of the ninth century Avicenna tells us that "the flesh of the serpent when duly prepared forces all the humors to depart. It also prolongs life, maintains the faculties of the body, and preserves youth." Roger Bacon, several centuries later, expressed great faith in viperine flesh which, however, he observes, should not be taken except when the sun ascends.

Among the older methods adopted for the prolongation of life was the Gerocomic which held that the primitive life-giving substance was to be found in its purest state in the breath of innocents. Thus the custom arose of breathing in

new life and vigor through close contact with the young. David, King of Israel, employed this method to prolong his life. Hermippus, who is said to have conducted a girls' school in Rome, thought that by inhaling the pure breath of the young maidens he had prolonged his life a number of years. Even in the latter part of the eighteenth century, Boerhaave assures us that by bringing the old in close proximity to the young the old are greatly invigorated.

During the latter part of the eighteenth century, the French capital was thrown into a state of great excitement by Frans Mesmer, who conceived the idea of making magnets which he sold as a remedy for toothache, neuralgia, rheumatism, etc. Being successful in this venture he went a step further and maintained that great magnetic force emanated from his person. He brought forward many people who proclaimed his healing power and who were firmly convinced that at will he could dispense pleasure or pain to mankind.

One of Mesmer's disciples wrote of his powers as follows:

> Behold a discovery which will bring invaluable advantage to mankind and eternal fame to its author! Behold a general revolution! Other men will inhabit the earth; they will be checked in their careers of life by no weakness and will be acquainted with our evils only by tradition; mothers will suffer less from pains of childbirth, and will bring forth stronger children who will possess the activity, energy and courage of the old world. Animals and plants, alike, susceptible to the magnetic virtue, will be free from disease; flocks will more easily increase; the productions of our forests will have more vigor; the trees will produce more beautiful fruit. The human mind in possession of this agent will perhaps present to nature effects still more wonderful. Who can know how far its influence may extend?

A commission was soon appointed by the French Academy of Science, under the direction of Dr. Franklin, to investigate the claims of Mesmer. The mystery was solved, the false claims discounted and all that remained was "animal magnetism," or, as we say, hypnotism.

The wanderings of Ponce de Leon in quest of the fountain of eternal youth, the transformations of the Navaho's revered goddess who grows old and at will becomes young again, the eating of powdered mummies, self-inflicted tortures, burning of witches, all belong in the same general category. Folk-lore and history are filled with attempts to restore youth, prolong life, rid the body of disease and drive out evil spirits. The earth, the air and the heavens were thought to be the abiding places of illness. Old age, disease and evil were thought of as entities restlessly flitting hither and thither, hovering over and descending upon mankind either by chance or at the behest of enemies, witches, demons or angry gods. Pleadings and prayers, infusions and balsams, extracts and excrements, talismans and magnets, ding-dongs and drums, dances and contortions, beatings and burnings were among the remedies, gentle and harsh, which were used to drive them away. The administration of these remedies was in the hands of priests, poets, philosophers, magicians, physicians and mobs. Disease was not understood, its real causes were unknown. Over the entire field of medicine there hung a dense cloud of mysticism.

It should not be inferred that the search, carried on during all these years, had been fruitless. Indeed there was a great residuum of observations which even to-day is undergoing winnowing and sifting in the hands of medical science. Moreover, the foundation of modern medicine had been laid through the work of Hippocrates, Aristotle, Galen, Vesalius and others. Above all, the belief has steadily grown that an elixir of life could not be found.

About the middle of the eighteenth century, scientific inquiry was begun with a view of ascertaining the maximal age which man had actually attained.

Haller, the great physiologist, stated that there were many well-authenticated instances in which man had attained an age of about one hundred and fifty years. James Easton, in the closing years of that century, published the names of seventeen hundred and twelve persons who lived for over one hundred years. Among these were fifty who had lived about 150 years; five 160, and two upwards of 170. There are doubtless many errors in Easton's records, as Thoms has pointed out. The case of Peter Torton, of Temesware, Hungary, who is said to have died at the age of 185 and that of John Roven at 172 and his wife at 164 may be ascribed to the overzealousness of the town to increase its population. We have, however, the testimony of most trustworthy men that Thomas Parr attained a very old age, possibly 152 years, as claimed. Harvey, who did the autopsy, was inclined to believe that the age given was nearly correct. The account of Henry Jenkins, who reached the century and half mark, as reported by Dr. Robinson, was accepted by the Royal Society and published in the "Philosophical Transactions" in 1696.

There is no published compilation of the number of centenarians who died during the nineteenth century. Here and there are suggestions which lead us to infer that the number must be considerable. In France statistics show that nearly one hundred and fifty deaths occur annually of people who have lived beyond one hundred years. In England and Wales the deaths of about one hundred annually are reported. The census of 1900 records three thousand five hundred and four centenarians living in the United States, while that of 1910 gives three thousand five hundred and fifty-five. The census of 1920 records 895 deaths of those who lived beyond one hundred years. At present it is not at all unusual to see the deaths of well-authenticated centenarians recorded in our daily papers.

In the latter part of the eighteenth century, the eminent naturalist, Buffon, undertook a study of life cycles of various animals as compared with their growth periods with the hope of obtaining facts which might throw new light on the life cycle of man. He concluded that most animals live six or seven times as long as it takes them to reach maturity. Flourens later worked over the same ground and claimed that growth ceases when the epiphyses become united with the bones. This union, according to Flourens' data, takes place in the dog at two years, in the lion at four, in the horse at five, and in man at about twenty. The normal life cycle of the dog is from ten to twelve years, of the lion twenty and of the horse about twenty-five or about five times the duration of growth. Accordingly, man ought to live about one hundred years.

Later investigations show that in man this union often does not take place until twenty-five, so that the normal life cycle from the standpoint of comparative longevity should be something over one hundred years. The evidence gathered from all sources seems to show that scientists have not widely erred in assuming that man should have a normal life cycle of not less than a hundred years. That he frequently has reached a considerably greater age is beyond question.

Many attempts have been made, during the last two centuries, to ascertain some of the factors which have conduced to longevity, such as geographical location, mode of living, diet, etc. From the study of the lives of nearly two hundred centenarians we gather but little. As to location, there are some differences. Eastern Europe has furnished more than Western Europe, although of a lower grade of civilization. In Western Europe, Greece has furnished a large number, while Switzerland has had but few. As to mode of living, the great majority came from those who led simple lives;

the agricultural classes furnished an exceedingly large proportion. As to diet, some ate one meal per day, others four or five. A few ate large quantities of food, the greater number a small amount; some lived entirely on vegetables, others to a great extent on animal foods. A few indulged in alcoholic drinks; others were total abstainers; most were temperate.

Hofmann, the physiologist, after reviewing all the work was unable to isolate the factors conducing to longevity. The best rules which he could offer were these: "Excess should be avoided in everything; old habits should be respected; pure air should be breathed; pure food should be taken; food should be adapted to temperament. Keep the heart light, the mind content and the conscience free." It should not be forgotten that senescence is in no small degree a state of mind as well as a condition of body. The physician's serious mien, his dubious shake of the head, and the confidential whisper, "You know, he is over seventy," have often lessened both happiness and life.

Science had well-nigh relinquished the hope that a panacea might be found when in 1880 the Society of Biology in Paris was astounded by the announcement of the well-known physiologist, Brown-Séquard, that he had discovered an elixir of life. It was and is a well-known fact that the atrophy or removal of certain glands such as the thyroid and the spermatic glands produces mental and physical debility. Brown-Séquard asserted that the weakness of old people depends, to some extent, on a natural series of organic changes but largely upon the gradually diminishing activity of these glands. Led by these postulates, he made an elixir from the seminal glands, the seminal veins, and the seminal fluid, which when injected beneath the skin had wonderful effects on a large number of experimented animals. Also he, in his own person, experienced a remarkable return of youthful activity, after its administration. Dr. Variot, of Paris, treated a number of aged people with the elixir and, although they were wholly unaware of its use, they were markedly rejuvenated. The use of the elixir spread like wild fire, physicians clean and unclean began to give hypodermic injections of the elixir and blood poisoning often followed. The results were not permanent. The elixir became capital for the charlatan, the merry-andrew, the cartoonist and even the vaudevillist.

Around the sex glands have centered all sorts of speculation and some experimentation. Our best deductions are that energy, both muscular and mental, are at highest tide during the period when the sex glands are most active, and conversely muscular and mental activity decline as these glands become less active. The experiments of Steinach, Voronoff and others indicate that a transplantation of active glands temporarily rejuvenates. Some twenty years ago, Dr. Goheen and the writer found that spermatozoa from the young rat when injected into the peritoneal cavity of an old rat increased the period of motility of the old rat's sperm. But the stimulus lasted only for a short time, following the injection.

From the evidence at hand, one would probably not go far afield in predicting that the day is not far distant when the gland jag will again be placed in the same category as the corn whiskey jag.

Brown-Séquard was the last scientist to cherish the hope of finding a panacea for old age. The next efforts in this direction were the attempts to find a single remedy for a group of diseases. This is well illustrated by the work of Metchnikoff, of the Pasteur Institute, who attempted to show that the large intestine, including the caecum, was evolved as a reservoir so that animals could retain large quantities of fecal matter and thus could run long distances without inconvenience. Man has inherited this useless

structure. This author cites many physiological experiments to show that there is no absorption of food materials in this part of the bowel, and that the mucus secreted is best interpreted as a lubricant. The accumulation and retention of fecal matter serves as a nidus for general fermentation and putrefaction and especially butyric fermentation which, in turn, gives rise to a number of diseases.

In order to lessen these processes and especially to neutralize the butyric fermentation, Metchnikoff says it is necessary to set up some counter process. Experiments show that one of the most effective of these is lactic fermentation. To induce this through simple means the author advocates the drinking of quantities of sour milk. It should not be inferred that Metchnikoff claims this as a panacea. He is careful to limit its use to the prevention of those diseases which result either directly or indirectly from intestinal autotoxins.

Efforts of a similar nature, that is, to find remedies for groups of diseases, are to be found to-day in the emphasis which is being placed on the so-called endocrine glands. Some maintain that senility is an epoch of ductless gland insufficiency. We know that the thymus gland is associated with the period of most active growth and then gradually disappears. The thyroid and pituitary glands are intimately associated with dwarfism and giantism. Horsley thinks the conservation of the thyroid gland is an essential for long life. We know something of the functions of the spleen and adrenal; less of the tonsil and corpus luteum and prostate.

The various interpretations of one member of this group—the so-called pineal gland—or are illustrative of our imperfect knowledge of the other members. The pineal gland to-day is believed to secrete some constituent of the cerebrospinal fluid. Yet we do not actually know that it secretes anything. Descartes thought it to be the seat of the soul; later when the brain-sand was found, the idea arose that this sand was ballast for effervescent dispositions. Then came the suggestion that the pineal body controlled waking and sleeping; then that it is an organ for the perception of temperature; then an organ in which the sense of return or homing is located; then the seat of a sixth and unknown sense; then a median or third eye; and finally a pair of fused embryonic eyes. All of which serves to emphasize the fact that endocrinology is a most fruitful field for investigation!

In recent years science has begun the study of old age from the standpoint of structural changes in the organs, tissues and cells. All know that the bones are more brittle and more easily fractured in the aged. This is due to the bones having become more calcareous. In the same way, the arteries undergo striking changes. The saying that "a man is as old as his arteries" is well founded. The arteries in old age become thickened, hardened and lessened in caliber from fibrinous and calcareous deposits, producing the disease called arteriosclerosis. This is most easily detected in the large blood vessels, but all, even the most minute capillaries, undergo the same gradual change.

This degeneration of the blood vessels results in a decreased supply of blood to all parts of the body. The blood supply to the brain is diminished, its nutrition is lessened, and its functions thus impaired. The vigorous brain of middle life gives way to the feeble intellect with its loss of memory and confusion of ideas so characteristic of old age. Not only is this true of the brain but the nerves themselves show a decrease in activity. The activity of the sympathetic system declines. The spinal nerves, which have to do largely with feeling and motion, conduct impulses less readily. The lessened blood supply to the stomach and other parts of the alimen-

tary system results in decreased powers of digestion and absorption with a corresponding decrease in nutrition. The elimination of waste materials is lessened so that such structures as the kidneys may become poisoned by their own secretions.

Since in the further presentation the problem must be considered from the standpoint of changes in the cellular elements, let us think of a drop of blood which contains many millions of cells. These cells are of two kinds, the red and the white. There are some millions of the red corpuscles and some hundreds of thousands of the white corpuscles in each drop of blood. These latter have the form, when they are killed and stained for microscopic examination, of irregular stars. In life they change their shape by their own inherent quality. The substance of these little stars is called protoplasm. Each of these stars or cells has at its center a little ball which is called a nucleus.

When disease-producing bacteria have gained entrance to the body, a great army of these white cells, which ordinarily are floating in the blood, crowd through the walls of the blood vessels and hasten to the spot where the bacteria are located. They immediately engage in conflict with the bacteria and consume them. By special staining we can determine the number of bacteria which each white blood corpuscle is able to devour. Thus we have a health index as far as these cells are concerned.

These white cells of the blood usually attack only a foreign foe, but at times they turn upon their fellows, the special cells, which they have hitherto protected, and destroy them. This point is forcibly illustrated by a well-known change which occurs in the animal kingdom. All of us know that the common pollywog or tadpole changes in some way into a frog. The most obvious external changes are the appearance of legs and the disappearance of the tail. This latter change is due to the fact that an army of white blood cells "marches" into the tail and devours the other cells which form it.

We know little of these white blood cells and their work in the body; they are always present in inflammation and when wounds are healing. Some have maintained that these cells in some way stimulate dormant cells into activity. They seem to play an important part in both constructive and destructive processes. Scientists have tried to find some means of controlling the activities of these cells and some progress has been made in that Metchnikoff some years ago announced the discovery of a special serum which retards their activities, but how to increase their activity is a problem as yet unsolved.

Roux, the celebrated anatomist at Halle, some years ago pointed out that the highly specialized cells of the body, such as the gland cells, muscle cells and nerve cells, are in constant struggle with a great group of connective tissue cells.

These cells, like the white blood corpuscles, belong to the simple or wandering type. Metchnikoff confirmed and extended these observations and says: "In growing old, the same condition is always present: the atrophy of the higher and specific cells of a tissue and their replacement by a lower type. In the brain, nerve cells disappear; that is to say, cells which subserve the higher functions such as intellectuality, sensation, control of movement, are replaced by cells of a lower type. In the liver, the hepatic cells, of great importance to the nutrition of the organism, yield to the simple cells. In the kidneys, the simple cells invade and block the tubules through which the elimination of waste matter is accomplished. In the ovaries, the ova, the specific elements which serve to propagate the race, are similarly eliminated and replaced by simple cells. In other words, a conflict takes place in our bodies between the higher cells and

the simpler or wandering cells of the organism, and the conflict ends in the victory of the latter." Thus it would appear that one means of deferring old age would be to strengthen the special cells of the organism and to weaken the aggressive capacities of the simple cells. Metchnikoff warns us that this is not presented as a definite, but as a possible solution of the problem, and is offered for consideration like many other hypotheses on scientific questions.

The changes occurring in the special cells of the body, as it passes from the stage of greatest to that of least activity, are not easily interpreted. In the first place, most of the cells of our bodies do not remain for the entire life cycle but are frequently cast off and replaced by new ones. But this is not the case with some, such as the nerve and muscle cells, which live as long as the organism maintains its integrity. The changes in the cells of the spinal ganglia, which belong to those nerves carrying sensation, are very striking, as shown by Hodge and others. As they grow old, they become smaller, their nuclear material diminishes, and the protoplasm becomes vacuolated. It is well known, too, through the discoveries of Nissl and others, that the active nerve cells, both along the spinal cord and in the brain, possess bodies which are considered as stored-up food material. Marenescho and others have shown that these bodies are greatly diminished in both size and quantity in old age.

The writer's studies, on the structural changes taking place in the growing old of muscular tissue, show that in the young and growing muscle cell a unit of nuclear material is in physiological equilibrium with two or three units of protoplasmic material, while in the old muscle cell, when growth has ceased, a unit of nuclear material is in physiological equilibrium with twenty or thirty units of protoplasm. When an old muscle cell is partially destroyed its destroyed portion can be replaced only when nature restores the equilibrium of youth. Minot believed that old age is a phenomenon which makes its appearance in childhood. "The nucleus atrophies from our youngest age to old age, it continually diminishes in volume, whereas the protoplasm becomes more abundant. In the perpetual consumption of the nucleus is revealed the reason of our getting old and dying."

Structural changes as indicated in dead and artificially stained materials are but crude indices of far more subtle changes. Biophysics teaches that heat, light, electricity, osmosis, pressure, etc., profoundly modify processes. Biochemistry teaches that the rates of protein, carbohydrate, fat metabolism and the action of the precious accessory vitamins are all definitely related to growth. The mysterious hormones, which correlate the activities of the sexual organs, the mammary glands and the thyroid gland, lead us into an almost unknown field. Way back in the earlier stages of individual life, certain exciters or tonines speed up cell division in certain groups of cells. This is visible in the formation of the blastopore, neural folds, the extremities and many other structures. If we press our inquiries back to the starting-point of the individual—the fertilized ovum—that marvelous vehicle which carries the parental qualities on into the offspring, we are in the presence of a microcosm, an almost unknown world, whose materials, potentialities and forces baffle the human mind. Until we know the materials and forces operating in some one living cell at some one time in its life, we shall be unable to evaluate the many factors which modify the life cycle of the organisms.

Not only must we push our inquiries further and further into this invisible world, but also we must increase our efforts in other lines. Through the avenues of empirical medicine and sanitary science, the expectancy of life has

been greatly increased. According to our best information, the average span of life was increased about four years during the seventeenth and eighteenth centuries, about eight years in the first three quarters of the nineteenth century and about sixteen years since 1875. While we have thus made much progress, we still lack information in easily accessible fields.

We keep the records of trotting horses and hunting dogs with great care and search back, for generations, to find the strong and weak points that we may, through a careful observation of the laws of heredity, accentuate the good and eliminate the bad. We heralded, with admiration, the work of Luther Burbank in making new and better fruits, through a careful study of the methods of perpetuating the desired qualities, which are found here and there in the parent fruits.

But the study of man, with a view of preserving and accentuating, in the offspring, the sterling qualities found among the ancestors, has not received serious consideration. Yet we know that heredity is one of the chief factors in longevity. There should be some means of recording the physical condition of each individual at frequent intervals. Every physician should be required to send to some bureau the precise data regarding his personal findings in the diagnosis and treatment of each disease, and such data should be placed, at once, in the hands of the physician who next comes in contact with the same patient. We could, thereby, anticipate many diseases and prevent or cure them in their incipient stages. We thus could obtain information as to the sequence of diseases. We know that measles predisposes to tuberculosis; rheumatism is often the forerunner of heart disease; scarlet fever of kidney trouble. By the collection and study of a great body of data we might be able to ascertain what effects, if any, the excision of organs and the administration of drugs have upon body functions, and whether they predispose toward other diseases. It may be said that the use of the statistical method in studying the problems of disease and old age has only begun.

Science makes tardy progress in the prevention and cure of disease because she is shown but little favor. It is not difficult to obtain millions of dollars for good roads; the improvement of rivers and harbors; the extension of commerce; the fostering of agricultural interests; the enlargement of army and navy. Yet, it is extremely difficult to obtain adequate funds to develop the vitalizing force for all these—human efficiency.

The trouble is, mankind has not as yet full confidence in medicine. Masquerading, under her name, are thousands of quacks and charlatans who bring her into disrepute. Quackery, which is outside the medical profession, is a great evil, but its consequences are not comparable to that which is inside. Nothing is so much needed in medicine to-day as apostles of sincerity—of stern and uncomprising animosity to all forms of quackery, both without and within the profession. How refreshing such frankness as that of Ambroise Paré: "I tend him, God cures him."

Again, when medical science is confronted with common diseases, such as whooping cough, measles, scarlet fever, pneumonia, cancer, paralysis and mental disorders, she, time and again, shows her weakness. Her strength, however, is seldom brought prominently before us. We are not impressed by the diseases we do not have.

Were the discoveries of medical science taken from us, one by one, until we returned to the condition of the middle ages, we should have a profound respect, if not reverence, for her achievements. If we were deprived of the result of modern dentistry alone, we should have a tenfold increase in the number of dyspeptics and rheumatics. Do away

with spectacles and the operation for cataract, let the eyesight of the aged be impaired or destroyed, and again happiness and life are both lessened. From all our therapeutic agents, take away only quinine, mercury and salvarsan, and malaria and syphilis will again take frightful toll of human lives. Forget the work done on hookworm and trypanosomes, and millions of afflicted in our Southern States and in South Africa will lead useless lives until death brings relief. Discard the work of Jenner, and smallpox will again carry away its annual hundreds of thousands. Reject the laborious results of Sternberg, Saranelli, Reed, Carroll, Gorgas and Noguchi, and yellow fever will again mow down its victims so rapidly that the long trenches will be piled deep with nameless dead. Make it impossible to study further the means of preventing and curing consumption, and this deadly Moloch will increase again its toll of thousands of human beings each day. Deprive us of the discoveries of Kitasato and Yersin, and let us remain in ignorance of how the plague is carried and again witness, as did our forefathers, this great tidal wave of death, as it sweeps country after country. Abolish the treatment for tetanus and hydrophobia, and witness again those terrifying scenes that caused whole communities to gather in weeping and prayer. Blot out the work of Behring, and diphtheria will again take our loved ones, by the score, where it now takes but one. Forget the work of Pasteur and Lister, neglect asepsis in surgery, and nine out of ten who go to the operating table will pass on to the grave. Finally, let us reject the discoveries of Wells, Morton and Simpson and surgery will return to the days before anesthetics, when it was the most awful vivisection, when the operating room was filled with heart-rending scenes: the moans of friends, the wails of kindred, the screams and struggles of the tortured patient who, bereft of reason, was bound to the operating table with straps and cords, while a leg or arm was being sawed off.

From the many achievements of medical science, these few have been cited to show that she has done much and to suggest that she can do more. Through sanitation and hygiene and through better medicine and surgery she has wonderfully reduced the death-rates of medieval days and will reduce the present death-rate in the days that are to come.

The people to-day, as never before, appreciate the fact that the greatest wealth is health. The time is not far distant when each state will have installed the machinery, in the way of clinics, laboratories and libraries, for the study of the causation of disease and its prevention; but all the energy and money expended in clinics, libraries and laboratories will be of little avail unless research ideals form the heart and soul of these organizations. The workers—clinicians, investigators, teachers and students—must be inspired by a desire to know truth for truth's sake. There must be a love for knowledge which far transcends its practical application.

It is thus that we owe wireless telegraphy not so much to Marconi as to Maxwell and Hertz. Our mastery of the air is largely due to the studies of Langley, yet all he realized of the practical application of his studies was an occasional bath in the Potomac. John Hunter's work in comparative anatomy evoked the sneers of his professional contemporaries, but to-day we know that comparative anatomy and comparative physiology have led to the solution of many problems because by such studies they were removed from the complexities which frustrate our researches in the higher organisms.

The studies of Pasteur, on spontaneous generation, were undertaken in this spirit of knowledge for its own sake. Let us hear the words of this great

scientist as he speaks before the Medical Congress in London, on August 8, 1881:

I should be guilty of ingratitude and false modesty if I did not accept the welcome I have received among you as a mark of homage paid to my labors during the past five and twenty years upon the nature of ferments—their life and their nutrition, their preparation in pure state by the introduction of organisms under natural and artificial conditions—labors which have established the principles and the methods of microbiology, if the expression is allowable. Your cordial welcome has revived within me the lively feeling of satisfaction I experienced when your great surgeon, Lister, declared that my publication in 1857, on milk fermentation, had inspired him with his first ideas on his valuable surgical method. You have awakened the pleasure I felt when our eminent physician, Dr. Davaine, declared that his labors on splenic fever had been suggested by my studies on butyric fermentation and the germ which is characteristic of it. Gentlemen, I am happy to be able to thank you by bringing to your notice a new advance in the study of microbiology as applied to the prevention of transmissible diseases—diseases which, for the most part, are fraught with terrible consequences, both for man and domestic animals . . . It is through this inquiry that new and highly important principles have been introduced into science concerning the views on the contagious quality of transmissible diseases.

Ehrlich has well said that our further knowledge concerning transmissible diseases is little more than diligent empiricism based upon these fundamental studies. It might well be added that Pasteur's discoveries have done more to prolong human life than all other discoveries combined.

I have given these few illustrations for the purpose of further emphasizing the great need in our institutions of learning, of not only accentuating practical knowledge but also the creation of a great fund of knowledge whose present returns are solely the satisfaction of knowing.

When the laws of nature are so well understood that the life cycle now given to the few shall be given to the many, will our attitude toward old age have changed? Will man be content with a life cycle of a century? Will not hope, happiness and enchantment give way, as now, to doubt, sadness and anxiety? The answer[2] is found in lives like that of Confucius, who is said to have described himself as a man who, in the eager pursuit of knowledge, forgot his food; who, in the joy of his ideals, forgot his sorrows and did not even perceive that old age was coming on. Here is an example of that philosophy which counts years by life, instead of life by years. Time may measure physical efficiency, but time can not measure ideals, hopes and dreams.

[2] Another answer is that emphasized, I think, by Haldane to the effect the great sorrows and regrets of life come from its impaired realization and its premature ending; that the organism which has completed its natural cycle faces death with equanimity; and that when science shall enable each man to live out in health and vigor his appointed days death in large measure will lose its sting.—E. P. L.

MEANING, METHODS AND MISSION OF MODERN MATHEMATICS

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I

THE modern conception of mathematics has not yet found its way into the textbooks. Even lexicographers, who should know the meaning of words, and on whom most of us depend for authoritative definitions of unfamiliar terms, fail to inform us.

Murray's New English Dictionary conceives mathematics in a strict sense to be "the abstract science which investigates deductively the conclusions implicit in the elementary conceptions of spatial and numerical relations." This definition fails on each of three counts: The conceptions of mathematics are seldom elementary; they are not limited to spatial and numerical relations; the investigations do not generally proceed deductively.

The Century Dictionary, having defined mathematics as the science of quantity, speaks of qualitative mathematics as mathematics kept rigorously free from every quantitative idea. How a branch of the science of quantity can be kept free from quantitative considerations is left for the reader to explain to himself.

Both the definitions cited suffer from arrested development.

To say that mathematics is the science of quantity is like saying that geometry is the science of earth-measurement, since it was to the practical enterprise of land-surveying that geometry owes its origin. It is like saying that trigonometry is the science of triangles, since it was the attempt to solve triangles that gave the science its first impetus, or that algebra is the science of equations, inasmuch as the practical need of solving equations gave birth to algebra.

Mathematics, it is true, originated in the contemplation of magnitude and form. And everything in which quantity or form predominates was at one time considered a part or a branch of mathematics. Thus it came about that astronomy, music and optics were at one time considered mathematical studies.

To escape the dilemma of calling grocers and tailors mathematicians, because they also deal with quantity and form, it was found necessary to distinguish between direct and indirect measurement of quantities. Mathematics was now thought of as dealing with quantities at a distance, quantities nonexistent, or inaccessible, such as planetary and stellar magnitudes.

This was the view espoused by the famous author of the Positive Philosophy, who boldly announced in his first chapter of his first book, "the object of mathematics is the indirect measurement of magnitudes, and it purposes to determine magnitudes by each other, according to the precise relations which exist between them."

But the ink had scarcely dried on Comte's pen when von Staudt discovered and expounded his "Geometrie der Lage," in which quantitative ideas are completely ignored. Von Staudt's book was published in 1847 and in the same year appeared Boole's "Mathematical Analysis of Logic," the forerunner of his immortal "Laws of Thought," another mathematical work dealing with neither quantity nor form.

Von Staudt's work, perhaps as great and far-reaching in its consequences as Boole's, aroused but little philosophic comment, but Boole's work captivated

the logicians. Russell says it was Boole who *discovered* pure mathematics. Boole was followed by Couterat in a book entitled "The Principles of Mathematics," in which the author tried to show that all mathematics is reducible to logic. Russell proclaimed that "the fact that mathematics is symbolic logic is one of the greatest discoveries of our age and when this fact has been established the remainder of the principles of mathematics consists in the analysis of symbolic logic itself." Keyser in one of his addresses put the thesis in unmistakable terms when he said "Symbolic logic is mathematics, mathematics is symbolic logic, the twain are one."

The view that mathematics is logic and nothing but logic was quite generally accepted by mathematicians as well as by logicians during the last quarter of the last century. W. B. Smith pronounced mathematics the "universal art apodictic," Benjamin Peirce defined it as the "science which draws necessary conclusions," Felix Klein saw in it "fundamentally the science of self-evident things" and Whitehead "the development of all types of formal, necessary, deductive reasoning," and so without end. All agree that in substance the logicians were right.

Inspired by this assumed epoch-making discovery, there now followed in rapid succession the great masterpieces of logistics—Peano's "Formulaire," now in its fifth edition, the wordless book, which by the use of special symbols undertakes to reduce the various branches of mathematics to their irreducible elements, and Whitehead and Russell's "Principia Mathematica" with an aim even more ambitious, that of deducing the whole of mathematics from certain undefined mathematical constants and certain indemonstrable propositions, exactly nine of the one and twenty of the other, no more nor less. The first page of the first volume of Russell's "Principles of Mathematics" contains what is perhaps the most famous definition of mathematics ever advanced, a definition that might preserve its dignity even beside Spencer's famous definition of life. Russell's definition reads:

> Pure mathematics is the class of all propositions of the form "p implies q," where p and q are propositions containing one or more variables, the same in the two propositions, and neither p or q contains any constants except logical constants. And logical constants are all notions definable in terms of the following: Implication, the relation of a term to a class of which it is a member, the notion of *such that*, the notion of relation, and such further notions as may be involved in the general notion of propositions of the above form. In addition to these, Mathematics *uses* a notion which is not a constituent of the propositions which it considers—namely, the notion of truth.

In another place Russell tried to popularize this definition by putting it into the following paradoxical form:

> Pure mathematics consists entirely of such asseverations as that, if such and such a proposition is true of *anything*, then such and such another proposition is true of that thing. It is essential not to discuss whether the first proposition is really true, and not to mention what the anything is of which it is supposed to be true. . . . If our proposition is about *anything* and not about some one or more particular things, then our deductions constitute mathematics. Thus mathematics may be defined as the subject in which we never know what we are talking about, nor whether what we are saying is true.

Despite its wide-spread acceptance, this view of mathematics, set forth with such assurance, had soon to be modified. Why? Because it could not reconcile the two adamantine facts, that logic is barren, while mathematics is the most prolific of mothers. Said Poincaré:

> If all the propositions which mathematicians enunciate can be deduced one from another by the rules of formal logic, why is not mathematics reduced to an immense tautology? The syllogism can teach us nothing essentially new, and if everything is to spring from the principle of identity, everything should be capable of being reduced to it. Shall we then admit that the enunciations of all those theorems which fill so many volumes are nothing but devious ways of saying A is A?

After a most careful analysis of the premises of the logicians, in the second book of his "Science and Method," Poincaré comes to the conclusion that "logistics has to be made over and one is not sure what can be salvaged. It may survive as a branch of mathematics, but it has to abandon its claim to the overlordship of the mathematical world." Far from identifying mathematics with logistics, a closer examination reveals logistics as a water-sprout which has shot up from the parent tree—the giant Sequoia—oldest and mightiest of all the living creatures of the human mind.

What, then, is mathematics? Some think that because mathematics is a living, growing thing, it can not be defined. Says Shaw in his "Philosophy of Mathematics":

> The varied character of its content makes it impossible to reduce all mathematics to either arithmetic, geometry, logistics, calculus of operations, algebra, or transmutation. Nor can we define it more successfully as the study of form, or of invariance, or of functionality, or of theory of equations. It has been the effort of some to define it in terms of its sources, but it is not possible to limit it to the phenomena either of the natural world, the world of universals, or the mental world. Definitions that are based upon methods are no more successful, whether we emphasize its scientific procedure in observations, generalizations, and analogy, or its intuitive insight into the nature of things, or its deductive chains whose invulnerable links support the weight of modern science; nor yet is it wholly the spontaneous product of the imagination of an artist, whose material is not the solid granite of the architect, the flowing marble of the sculptor, the brilliant pigments of the painter, the rippling language of the poet, or the pulsing air of the musician, but is the delicate ether of pure thought. We cannot define it either by its applicability to the world at large, in any realm of validity. In none of these ways may it be defined, for it is all these and more. It may be studied in its varied aspects just as a man may be studied, but no definition based upon any one aspect will be sufficient to include the living creature itself. In short, mathematics is independent of any other branch of human knowledge. It is autonomous, and in itself must be sought its nature, its structure, its laws of being. Not in philosophy, not in science, not in psychology, not in logic, can we discover these things, but only in mathematics.

This view I do not concur in, for I think it may be shown that mathematics is characterized not, indeed, by its applications nor by its method, as has frequently been supposed, but by its content, by the nature of the material with which it works.

Let us then turn to some of the familiar branches of mathematics and see what it is that characterizes the notions that enter them.

Let us begin with arithmetic. Arithmetic deals with numbers, you say, but what is number? The term is used in every branch of knowledge, yet the mathematical concept of number is not knowledge gathered from experience alone. You may say that it is the symbol used to indicate the "how many," the one and only invariant of an aggregate whose members are subjected to all conceivable changes which do not destroy the separateness of the members. This definition is frequently accepted, but number thus defined is not number as the mathematician knows it. If number were an inherent property of physical aggregates and nothing more, then there would have to be a greatest number, all physical aggregates being finite. Then addition would be possible only so long as the sum of the addends does not exceed the greatest number. There could be then no general process of addition or of multiplication or of any other operation with numbers. To make arithmetic possible we not only abstract from experience, we go further and augment experience. And this process of augmentation is really the important thing, it is that which alone makes the science of arithmetic possible. We inject into our concept of number a property which is not the result of experience at all, namely, the property that for every conceivable number there exists one which is greater. Thus we see that number is not a physical property but a creature

of the thinking mind: it embodies the idea of never ending, of what we call the mathematical infinite. The basic concept of arithmetic is more than a mere abstraction. It is a concept suggested, to be sure, by experience, but it transcends experience, it is what we call an ideal construct.

Let us next turn to geometry. The subject-matter of geometry, it is said, consists of points, lines, angles, surfaces, etc. But what is a line? Certainly it is not the mark of ink or graphite that we spread on a sheet of paper to visualize the concept. The mark that represents the line has all the properties of matter—length, breadth, thickness, color, mass, density, etc. The geometrical line partakes of none of these. It can not be seen nor felt nor weighed nor measured. Is it then a mere abstraction? That is the common view but an erroneous one. For we may abstract from a material line all its physical attributes and what remains is not yet a line, but a segment of a line. So much experience suggests, but more is necessary before we have the concept which alone makes geometry possible. It is essential that in general two lines which lie in the same plane should intersect, and that three lines should form a triangle, while obviously two material lines will rarely ever intersect and it is a very remote probability that three random material lines should form a triangle. Abstraction once more is powerless, we again must inject into our concept the idea of never-ending—the mathematical infinite. For every imaginable point on the line we conceive of two others, one on each side of it, so that there is no first point and no last point. The line concept, like the number concept, is an ideal construct—suggested by experience to be sure, but transcending experience—a creature of the thinking mind.

As a third illustration, let us seek the origin of the axiom which constitutes one of the foundation stones of algebra: the axiom which asserts that things which are equal to the same things are equal to each other. In symbols: If $A = C$, and $B = C$, then $A = B$. Is this axiom the result of experience? Let us see.

Consider a band of color, say 100 feet long, which changes continuously from pure white at one end to black at the other. Suppose now that the band is divided into segments each one inch in length, 1,200 segments in all. No human eye is now able to distinguish between the colors of two consecutive segments. Let us denote the colors of successive segments by A, B, C, $\cdots$ Y, Z. Then so far as the human eye can judge, $A = B$, $B = C$, $C = D$, $\cdots$ $Y = Z$. Yet we know that $A \neq Z$, for A is white and Z is black. Experience in this case fails to verify the axiom that things which are equal to the same thing are equal to each other.

The example just cited is typical of all other attempts to verify the axiom experimentally. All such attempts are doomed to fail. Physical objects or phenomena can never be proven equal. Experiment can, at most, show approximate equality. For how can we compare physical objects? By means of sensation which is the only avenue of becoming aware of the objects and their differences. Sensations depend upon stimuli, and sensations are indistinguishable if their stimuli differ by sufficiently small amounts. A weight of ten grams and a weight of eleven grams are known to produce identical, that is, indistinguishable, sensations, so do two weights weighing eleven grams and twelve grams, respectively. But the sensations produced by two weights of ten and twelve grams are distinguishable. So far as we can judge by sensations things equal to the same thing are not necessarily equal to each other. In short, the axiom that things which are equal to the same thing are equal to each other can not be established by experience or experimentation. It is in fact a definition

in disguise, a definition of the concept equality, another ideal construct.

Now what has been said of the mathematical concepts of number, line and equality is true of every other mathematical concept, and this is one of the really distinguishing features of mathematics. Take any other mathematical concept which occurs to you—point, plane, circle, angle, sphere, continuity, invariance, infinitesimal, transformation—closely examined each of them is found to be an ideal construct, suggested by experience but not limited to experience, and it is because these ideas transcend experience that they are mathematical.

I have said that the axiom or postulate that things which are equal to the same thing are equal to each other is in reality a definition of equality. A similar statement can be made of any other axiom or postulate. Failure to recognize this truth has led to all kinds of confusion. If there is a difference between definition by postulates and direct definitions, it is this, that as a rule the former applies to a system of things. A system of postulates is an enumeration of the fundamental relations between the members of the system, from which may be derived all other properties of the system, and which, therefore, virtually defines the system.

Each system of postulates then defines the raw material of a field of mathematical thought and constitutes a branch of mathematics. The material thus defined is as truly ideal as if it had been directly defined.

Stuart Mill held that every definition presupposes the existence of the thing defined, existence being understood in the empirical sense. In defining a circle, Mill would say, we affirm that there are round things in nature. But it is obvious that a line, as we have defined it, does not exist in nature, nor does any other ideal construct. A mathematical construct exists if its definition involves no contradiction, a mathematical theorem is true, if it is consistent with the premises. From this point of view it is evident that no mathematical proposition can be established by experiment.

Astonishing as this assertion may seem to you, it is incontrovertible. Consider any mathematical proposition that comes to your mind, let us say the pons asinorum—the square on the hypothenuse of any right triangle is equal to the sum of the squares on the two sides. Suppose, contrary to fact, that it were possible to measure exactly the sides of physical triangles, and suppose that the sides of a million different triangles had been measured and that the theorem had been found true in each of the million cases, there would still remain millions of other cases among which there might be, for all we know, one or more triangles for which the theorem would not be true. If you say that this process would establish the truth of the theorem in the same way that other scientific truths are established and with as much certainty, I can only say mathematical truths differ from scientific truths in just this, scientific truths are never more than probable truths, mathematical truths are never less than absolute truths. We have here another distinguishing mark of mathematics.

The idea is worth pursuing further. Consider the set of mathematical propositions known as Euclidean geometry. They are characterized by the so-called eleventh postulate which asserts in substance that through a point one and only one line can be drawn parallel to a given line. This postulate may be replaced by this other: The sum of the angles of a triangle is equal to two right angles. Furthermore, it is easily shown that if there exists one triangle whose angle sum is two right angles the same is true of every other triangle. Euclid's eleventh postulate, therefore, is equivalent to the assertion: There exists a triangle whose angle sum is two right angles. In this form of the postulate we most clearly

recognize the futility of any attempt to prove it by experiment, for we have seen that no physical magnitude can be measured with absolute precision. We may, therefore, accept or reject the eleventh postulate. If we accept it, or its equivalent, namely, that the angle sum of a triangle is two right angles, we are led to a body of propositions which constitute Euclidean geometry; if we reject it, we must accept one or the other of two alternatives. If the angle sum of a triangle is not equal to two right angles, it must be either greater or less. Either assumption leads to a set of self-consistent propositions, the latter to a set of propositions known as the Lobatchevkian geometry, the former to a set of propositions known as Riemannian geometry. In terms of the parallel postulate a geometry is Euclidean, Lobatchevkian or Riemannian, according as we assume that through a point may be drawn one line, two lines or no line parallel to a given line. Each of these geometries is as true as the other, in the sense that they are equally self-sufficient. If we ask which of these geometries is true in the physical sense, that question has no meaning, for we have seen that geometry does not deal with physical objects, nor with physical properties. As Poincaré puts it in one of his essays, "the question as to which geometry is the true geometry is as meaningless as the question whether the metric system or the English system of measurements is the true system."

This example has been dealt with at some length in order to show that there is no essential difference between direct definitions and definitions by postulates. Postulates are conventions, limitations, if you please, which the mathematician imposes on the creatures of his imagination. These creatures are real only in the sense that they are conceivable; the theorems which he deduces regarding them are true only in the sense that they are consistent. It is this property that enables the mathematician to exercise absolute freedom in the choice of his material and the choice of his postulates. This is what is meant when we say that mathematics is an autonomous science, that the essence of mathematics lies in its freedom.

Now because mathematics deals with ideal constructions, and exercises the utmost freedom in the choice of its material, it has been supposed that this choice is arbitrary or capricious. Indeed, there is a wide-spread suspicion that a great deal of mathematical theory is entirely unrelated to life or to the material world. Some definitions, as Pieri's of mathematics as the hypothetico-deductive science, or Russell's of mathematics as the class of all propositions of the type 'p implies q', do seem to warrant the view that one set of conceivable definitions, one set of consistent postulates is as legitimate a starting point for a mathematical investigation as any other. Such a view, however, reduces the principle of "science for science sake" to an absurdity. An aimless concatenation of random consistencies would be as fruitless as the pastime of constructing anagrams or cross-word puzzles.

The mathematician exercises freedom, but it is freedom tempered by wisdom. From among an infinitude of conceivable ideal constructs, he is guided in his choice by a discernment of what is important, by a delicate discrimination of what is typical, by a penetrative insight and intuitive perception which enable him to single out the essential characteristics of a phenomenon or set of phenomena whose explanation is sought by the inquiring mind. Thus the postulates which form the basis of the various systems of geometry are not arbitrary propositions, but reasonable propositions, as Klein calls them, which have their origin in space intuition. For this reason the theorems of geometry apply more or less accurately to physical space,

they constitute the ideal handling of space relations.

Mathematics, then, is the ideal science, the science par excellence, which furnishes, as it were, the framework, the patterns which underlie the manifold phenomena of the physical world. It is a hyper-world, a super-sensuous world, the most stupendous and sublime of all fictions, yet a fiction which is true to reality, which matches reality at every point. It replaces the obscure images of sense by well-defined counterparts, and the vague and fleeting objects of the perceptual world by ideal constructs, constructs amenable to precise treatment. Mathematics in the main occupies itself with the discovery of ideal relations which are approximately matched, asymptotically approached, we might say, by the phenomenal universe.

II

Let us now turn from the meaning of mathematics to a brief discussion of its methods. The popular view, sanctioned by such definitions of mathematics as most dictionaries give, is that mathematics is the science of deduction par excellence, a view which culminated in the theory that all mathematics is logic. This view does indeed account for the perfect rigor of mathematical conclusions, but it leaves one at a loss to account for the endless variety of its astonishing results. This view, as we have already seen, involves an irreconcilable contradiction. A logical mill grinds only what is put into the hopper—it can change the form but can add nothing to the substance. What, then, is the source of the endless vistas of new relations, new properties, new truths which the mathematicians produce from an apparently inexhaustible store? The contradiction can only be removed by accepting an entirely different view of the methods by which mathematics proceeds in its discovery of truth.

The reason for this mistaken view that mathematics proceeds by deduction is due to the circumstance that the results of mathematical investigations have been traditionally invested in deductive form. It was the method which Euclid chose in compiling his Elements of Geometry. It is the form in which Archimedes made known to the world the fruits of his labor. The great weight of his example established the procedure for others, until it has become the vastly predominating, if not the exclusive form, in which the results of mathematical inquiries are cast before they are published. But every mathematician knows that the method of mathematical exposition is seldom, if ever, the method of mathematical discovery. A finished demonstration rarely, if ever gives a hint as to how the results were arrived at in the first place. Deduction, it is now held by many, has frequently been deliberately chosen as the most effectual means of hiding discovery, a successful method of effacing all traces of the tortuous paths which preceded the construction of the finished highway. Or if I may change the figure, deduction is, as it were, the finishing process to which the mathematical product is submitted before leaving the factory, the veneering which covers up not only the blemishes and imperfections but also all details of construction.

A misconception once firmly intrenched and supported by eminent authorities, however mistaken, is difficult to dislodge. Was it not Huxley who said that the mathematician is occupied with nothing but deduction and verification since all the inductions he needs were completed ages ago? And again that mathematics "knows nothing of observation, nothing of experiment, nothing of induction, nothing of causation."

Yet I venture to show that deduction, far from being the exclusive method of mathematical investigation, is not even

its predominant method. Mathematical problems are more frequently solved by analysis than by synthesis and inductive reasoning far outweighs deductive reasoning. Actual discovery in mathematics proceeds by cooperative efforts of all the mental powers. Progress in mathematical investigations depends upon comparison and generalization quite as much as does progress in the physical sciences. And as in the physical sciences, so in mathematics, isolation, observation, classification, trial and verification are constantly employed.

In opposition to Huxley's view on a subject which he did not understand, let me quote the views of two mathematicians of the first rank: Sylvester, the father of American mathematics, said:

> Mathematical analysis is constantly invoking the aid of new principles, new ideas, new methods, not capable of being defined by any form of words, but springing direct from the inherent powers and activities of the human mind, and from continually renewed introspection of that inner world of thought of which the phenomena are as varied and require as close attention to discern as those of the outer physical world, . . . it is unceasingly calling forth the faculties of observation and comparison, one of its principal weapons is induction, it has frequent recourse to experimental trial and verification, and it affords a boundless scope for the exercise of the highest efforts of the imagination and invention.

The same view was voiced by Hobson in his presidential address before the British Association for the Advancement of Science in the words, "the actual evolution of mathematical theories proceeds by a process of induction employed in building up the physical sciences; observation, comparison, classification, trial and generalization are essential in both cases." To the charge that mathematics knows nothing of causation, Hobson said:

> The opinion appears to be gaining ground that the very general conception of functionality, born on mathematical ground, is destined to supersede the narrower notion of causation, traditional in connection with the natural sciences. As an abstract formulation of the idea of determination in its most general sense, the notion of functionality includes and transcends the more special notion of causation as a one-sided determination of future phenomena by means of present conditions; it can be used to express the fact of the subsumption under a general law of past, present and future alike, in a sequence of phenomena. From this point of view the remark of Huxley that mathematics "knows nothing of causation" could only be taken to express the whole truth, if by the term "causation" is understood "efficient causation." The latter notion has, however, in recent times been to an increasing extent regarded as just as irrelevant in the natural sciences as it is in mathematics; the idea of thorough-going determinancy, in accordance with formal law, being thought to be alone significant in either domain.

But why rely on authority where the facts are accessible to all? It is obviously true that many geometrical truths must have been the result of observation long before they yielded to demonstration. If proof were needed we might cite the fact that every child knows a considerable number of geometrical facts long before he takes up the study of demonstrative geometry. Such facts as that parallel lines are everywhere equally distant; that one side of a triangle is less than the sum of the other two; the propositions regarding the congruence of triangles; the essential properties of isosceles and equilateral triangles, and many others are matters of common observation. Who can doubt that such relations as those between the squares of the three sides of a right triangle, of the angles inscribed in a semicircle and multitudes of others, were observed to be true long before they were demonstrated mathematically? Surely, all applied mathematics proceed by observation, namely, the observation of order and regularity or periodicity and symmetry which attract attention and invite investigation. The observation that circles, ellipses, parabolas and hyperbolas can all be cut from the same cone incited the early Greek mathematicians to the pursuit of the marvelous relationships and proper-

ties of the conic sections. The path of a fixed point on a rolling wheel, actually seen or imagined, was the occasion which led to the elaborate theory of cycloids and trochoids. Certain relations observed while constructing his planetarium led Huyghens to conceive and develop the theory of continued fractions. If you will pardon a personal allusion, I will add that it was observation of the wonderful symmetry and beauty of the curves described by a toy called the wondergraph that suggested to me the conception of cyclic-harmonic curves, the theory of which absorbed my attention for several years.

Let us next consider generalization. Instead of being foreign to mathematics I consider it one of its most fruitful methods. Looking over a list of my own contributions in mathematics, I find that nearly one fourth of them originated in the attempt to generalize known results. My first doctor's thesis deals with an extension and subsequent generalization of the differentiation process. Differentiation is based on the assumption that all quantitative changes are due, or may be conceived of as being due, to accretions, that is, the increments of the variables under consideration are taken as additive. The limit of the ratio of corresponding additive increments of the dependent and independent variable is called the derivative, and this is the fundamental concept of the differential calculus. Now it occurred to me that quantitative changes could as well be thought of as due to expansion, and corresponding changes compared by means of their logarithmic ratios. The limits of such ratios I called quotiential coefficients, and I was able to show that it is possible to develop a complete calculus, whose fundamental concept is the quotiential coefficient, and that this calculus is not only self-consistent, but could be employed for the interpretation of natural phenomena quite as well as the differential calculus.

Later I was able to show that the quotiential calculus and the differential calculus are but two links in an endless chain of calculi. A slight modification in the so-called involution process leads to an infinite sequence of processes of which any consecutive three are related in precisely the same manner as are addition, multiplication and involution. Each consecutive three of this sequence of processes may now be employed to define a limiting process completely analogous to differentiation. This process I have called ratientiation, the corresponding calculus, the calculus of ratients.

Again the largest of my later papers which deals with the sums of products on n consecutive integers is a generalization of the results of a score of papers dealing with the sums of products of the first n integers. Incidentally during the course of this investigation I was led to a generalization of Wilson's theorem, one of the most fundamental theorems in the theory of numbers, and which had already been generalized in various directions. Each generalization, of course, extends the domain to which the theorem applies and, therefore, increases its usefulness.

I have chosen these two examples of the use of generalization in mathematical research from my own work because they happen to be examples that are easily understood. But it is not necessary to stop with examples. There are whole branches of mathematics which consist in a large measure of generalizations of known results. Take spherical trigonometry. All the theorems relating to spherical triangles are, in a sense, generalizations of the theorems relating to plane triangles. By making the curvature of the sphere equal to zero, any formula of spherical trigonometry goes over into a corresponding formula for plane trigonometry. Many of the theorems of analytical geometry of three dimensions are generalizations of corre-

sponding theorems in two dimensions. The theory of functions of a real variable deals with generalizations of concepts and theorems of elementary calculus. The theory of functions of a complex variable consists largely in the generalizations of theorems pertaining to real variables. In fact it would be difficult to mention a branch of mathematics which is not the outgrowth of the attempt to generalize known results.

Generalization, then, must be put down as one of the dominant methods employed in mathematical research. In fact, this might be anticipated from the outset. The mathematical concepts, as we have seen, are the combined results of abstraction and generalization. Generalization is so typical of mathematics that some one has said, "Whatever the mathematician touches he changes—you hand him one thing and he returns something different." It is this that makes it so difficult to follow a mathematical discourse and that frequently makes it appear as if the mathematician talks nonsense. It is because the things he talks about are no longer the things which you know by the same name, but generalizations of them. The things you call number, points, lines, angles, sum, multiplication, power, root, have grown into something quite different under his hands. He has extended, transformed, generalized each of these things and by so doing has created a new universe with properties and phenomena undreamed of before. What are complex numbers, quaternions, transcendental numbers, ideal numbers, transfinite numbers, matrices, vector systems, hyperspaces and the elaborate theories based upon them but the results of generalization, applying known results and laws to ever larger and more diversified categories of things?

One form of generalization is known by the same induction. If Huxley said that mathematics knows nothing of induction, Poincaré, one of the greatest mathematicians of all time, considered induction as the very essence of mathematics, the one principle without which mathematics as a science could not exist.

The veriest tyro in mathematics knows that induction is used incessantly as a method of arriving at new results. Every elementary text-book of mathematics abounds in theorems which the student is led to discover by induction before they are demonstrated. Illustrations are the theorems relating to the divisibility of the sum of two odd powers by the sum of the numbers; of the difference of two even powers by the sum and the difference, the binomial theorem for positive exponents, the theorems for the summation of series, and countless others. And induction as used as an aid in discovery in mathematics is of precisely the same type as that used by the naturalist or physicist. It consists in the anticipation of a general law or relation from a number of specific instances. The fact that mathematicians do not accept the results suggested by induction as finally established until arrived at by demonstration does not destroy the utility of the method as an aid in mathematical research.

Observation, generalization, induction are as essential and of as common use in mathematics as in deduction proper. Nor is experimentation entirely foreign to mathematical research. It is said that Archimedes determined centers of mass geometrical figures by actually balancing on points and knife-edges material solids representing such figures. Eratosthenes became famous through his experimental method of constructing a table of prime numbers. In geometry models and drawings are used constantly to aid the imagination in its grasp of relations, to anticipate new properties, as well as to verify theoretical results. As great a modern mathematician as Felix Klein charged metallic plates electrically in order to prove the existence of functions

possessing certain singularities. The distribution of the current on the plates, he reasoned, would correspond to functions of the type sought for.

While the use of experiment as a method of mathematics is, no doubt, limited, its use in verification is universal. He knows little of the methods employed by mathematicians and certainly has never seen a mathematician at work, who imagines that theorems spring forth full-fledged from the mathematician's brain. The most recondite theorems in number theory, the most abstract of all mathematical theories, are submitted to numerical verification whenever possible. Sometimes weeks are spent in the numerical verification of a theorem that can be stated in a single line. Such verifications are seldom published and frequently not even mentioned, yet it is safe to say that in the aggregate much more time is spent by the average mathematical investigator in trial and verification than is spent in the derivation of his theorems. Eminent mathematicians are on record as having resorted to thousands of trials to verify single elementary conclusions in probabilities.

I think we are now in a position to see why mathematics progresses by leaps and bounds even after centuries of evolutionary development. It is because mathematicians avail themselves of the methods that alone are fertile. "There was more imagination," said Voltaire, "in the head of Archimedes than in that of Homer." "The moving power of mathematical invention," said the great DeMorgan, "is not reasoning but imagination." In fact all the powers of the mind are marshalled to united effort, all the methods known to science are drafted into active service, for the advancement of mathematical knowledge, for the discovery of mathematical truths. It is only after new relations have been surmised, new theorems anticipated and new problems formulated that ratiocination can do its work, that strictly logical methods of thought are applied to complete the structure by giving it that permanent, imperishable form which characterizes the mathematician's work.

III

I now come to the third and final part of my subject—the mission of the modern mathematics. The term mission suggests that I am not thinking of the manifold material advantages which have accrued to mankind through the use of mathematics in the shop, the factory and the counting house; through its application to surveying, to navigation, to the building of aqueducts, canals, railroads, bridges and highways; or to the aid it has rendered the architect and the master builder; or the share it has had in the achievements of all forms of modern engineering, whether naval, civil, mechanical, hydraulical, electrical or aeronautical, which through their conquest of the physical forces of nature have immeasurably improved the living conditions of mankind. Nor am I thinking of the indispensable aid that mathematics has rendered to the other sciences, to physics, to astronomy, to chemistry, to statistical science and to the science of risks, many of whose problems are not even intelligible without a considerable knowledge of modern mathematics. Nor do I wish to dwell on the central rôle which modern mathematics has played in every serious attempt of modern philosophy to find a "cosmos in the seeming chaos of the physical universe." All these topics are worthy of separate considerations, but the present hour is all too short for that purpose.

In speaking of the mission of mathematics I am thinking of mathematics as a spiritual enterprise, which like religion and art ministers to a spiritual need. I want to dwell briefly on the share which mathematics has in those great human interests, those spiritual enterprises, to which we owe such permanent values, as

by universal consent, constitute the most cherished possessions of our race.

That mathematics deserves human regard on the same grounds as poetry, music or plastic art has been recognized from time immemorial. The Pythagoreans conceived of mathematics as the foundation and essence of all art. To them all order and harmony, all law and beauty were but as many different manifestations of number relations. This idea of the close relationship between mathematics and art became a commonplace among the Greeks. It was accepted by the great Aristotle, who, in his Metaphysics, takes to task those who deny that mathematics has anything to do with what is beautiful. "Of what is beautiful," he says, "the most important species are order and symmetry, and this the mathematical sciences make manifest in a most eminent degree." It was, therefore, probably no accident which attracted the great masters in art, notably Leonardo da Vinci, Raphael, Michel Angelo and Alfred Dürer, to the mathematical sciences; or a mere coincidence that the golden epochs in mathematics have always been nearly synchronous with the golden ages of art and literature.

Am I dealing with outworn creeds, with conjectures and doubtful generalities? Let me cite a few witnesses from among a multitude, who can speak with knowledge; for just as it takes a musician to judge fairly the performances of a Wagner or a Chopin, so no one can give a truer appraisal of the esthetic pleasures to be derived from mathematics than its devotees. "Mathematics, rightly viewed," says Russell, "possesses not only truth, but supreme beauty—a beauty cold and austere, like that of sculpture, without appeal to any part of our weaker nature, without the gorgeous trappings of painting or music, yet sublimely pure, and capable of a stern perfection such as only the greatest art can show. The true spirit of delight, the exaltation, the sense of being more than man, which is the touchstone of the highest excellence, is to be found in mathematics as surely as in poetry." Here we have a partial explanation of the community of delight of which Wordsworth must have been keenly conscious when he mused

> "On poetry and geometric truth,
> And their high privilege of lasting life,"

an idea further amplified by the philosopher-mathematician, Thomas Hill, in one of his essays when he says:

> Mathesis and Poetry are utterances of the same power of imagination, only the one is addressed to the head, the other, to the heart. Poesy is a creation, a making, a fiction; and the Mathematics have been called, by an admirer of them, the sublimest and the most stupendous of fictions. It is true they are not only μάθησις, learning, but ποίησις, a creation.

"Who that has studied the works of such men as Euler, Lagrange, Cauchy, Riemann, Sophus Lie and Weierstrass," asks Hobson, "can doubt that a great mathematician is a great artist?"

> However far the calculating reason of the mathematician may seem separated from the bold flight of the artist's phantasy [answers Lampe] it must be remembered that these expressions are but momentary images snatched arbitrarily from among the activities of both. In the projection of new theories the mathematician needs as bold and creative a phantasy as the productive artist, and in the execution of the details of a composition the artist must calculate dispassionately the means which are necessary for the successful consummation of the parts. Common to both is the creation, the generation, of forms out of mind.

Sylvester, the founder of American higher mathematics, himself a man of a highly developed artistic temperament, was ever conscious of the essential unity of mathematics and the fine arts.

> The world of ideas which mathematics discloses or illuminates, the contemplation of divine beauty and order which it induces, the harmonious connection of all its parts, the infinite hierarchy and absolute evidence of the

truths with which it is concerned [he exclaims] these, and such like, are the surest grounds of the title of mathematics to human regard.

And in another place he asks,

May not music be described as the mathematic of sense, mathematic as music of the reason? the soul of each the same! Thus the musician *feels* mathematic, the mathematician *thinks* music—music the dream, mathematics the working life—each to receive its consummation from the other when the human intelligence, elevated to its perfect type, shall shine forth glorified in some future Mozart-Dirichlet or Beethoven-Gauss—a union already foreshadowed in the genius and labors of a Helmholtz!

Expressions like the foregoing could be multiplied almost indefinitely, but one other must suffice. It is Boltzmann's answer to the query, Can anything be beautiful where there is not the slightest attempt at external embellishment? Boltzmann's answer is:

It is this very simplicity, the indispensableness of each word, each letter, each little dash, that among all artists raises the mathematician nearest to the World-creator; it establishes a sublimity which is equalled in no other art,—something like it exists at most in symphonic music. . . . How expressive, how nicely characterizing withal is mathematics! As the musician recognizes Mozart, Beethoven, Schubert in the first chords, so the mathematician would distinguish his Cauchy, Gauss, Jacobi, Helmholtz in a few pages. Extreme external elegance, sometimes a somewhat weak skeleton of conclusions, characterizes the French; the English, above all Maxwell, are distinguished by the greatest dramatic bulk. Who does not know Maxwell's dynamic theory of gases? At first there is the majestic development of the vibrations of velocities, then enter from one side the equations of condition and from the other the equations of central motions—higher and higher surges the chaos of formulas—suddenly four words burst forth "Put n = 5." The evil demon V disappears like the sudden ceasing of the basso parts in music, which hitherto wildly permeated the piece; what before seemed beyond control is now ordered as by magic. There is no time to state why this or that substitution was made, he who can not feel the reason may as well lay the book aside; Maxwell is no program-musician who explains the notes of his composition. Forthwith the formulas yield obediently result after result, until the temperature-equilibrium of a heavy gas is reached as a surprising final climax and the curtain drops.

Now if it be granted that mathematics has a place among the fine arts, it must have a share in the mission of all art, which I take to be the ministration to the esthetic needs of our race through the creation and revelation of beauty of whatever form. There is, however, still another domain in which mathematics is the chief, if not the sole, ministrant. I refer to the domain of pure intellection, the empire of rationality, the world of concatenated ideas, the only universe in which truth has a meaning.

For what is truth? I need not tell this company of the dismal failure of the search for truth in the world of phenomena. That truth can not be found in the world of sense and matter has been the universal verdict of philosophy throughout the centuries. We are not sure of the facts of nature, much less of its laws, on the contrary we are quite sure that things are not what they seem, and that the laws of nature are but man's attempts to reduce to a semblance of order what would otherwise be but "a big, booming, buzzing confusion," as James once called it.

Yet we are all conscious, too painfully conscious, of a craving for truth, for certainty, for permanence, for something that is stable and enduring. "The cry of the dying Goethe, 'More light, more light,'" says Dodgson, author of "Alice in Wonderland," "is the cry that, throughout all the ages, is going up from perplexed humanity, and science has little else to offer that will really meet the demands of its votaries, than the conclusions of pure mathematics." Mathematics has gradually evolved an ideal world, an ordered cosmos, closely matching though transcending the world of reality, a world amenable alone to the laws of reason, a cosmos in which order and consistency reign supreme. As

Wordsworth has it, "in verity, an independent world, created out of pure intelligence." In this world reason has built itself a home, a dwelling place, whither it can withdraw from the "dreary exile of the natural world." For are not mathematical truths eternal truths? Before the laying of the foundations of the world, and after the heavens shall have been rolled up like a scroll, the endless galaxies of mathematical theorems will shine forth as unchangeably true, as dazzlingly beautiful, as majestically pure and austere as on the days of their births. In this world of ideals, mathematics is symbolized by the Hercules of mythology who liberated the tortured Prometheus, shackled and chained to the rocks.

Clifford in one of his essays speaks of geometry as having been throughout the centuries "the encouragement and guide of that scientific thought which is one thing with the progress of man from a worse to a better state"—the encouragement through its revelation of a body of truth that can be absolutely relied upon, the guide, because it furnishes an ideal of perfection which has been the aim of every other science to approximate. The truth of this view is manifest on every hand. The chemicization of biology, the physicization of chemistry, the mechanization of physics and the mathematicization of mechanics are the successive steps in the gradual approximation of that rationalization of the world of phenomena to which mathematics has pointed the way.

Mathematics thus offers a partial response, and, I believe, the only conceivable response, to one of the three great aspirations of the human soul—the aspirations for the good, the beautiful and the true. And as religion has for its chief domain the search for the good and for its mission to minister to the moral needs of man, as art in its quest for the beautiful ministers to the esthetic life, so mathematics in revealing the meaning of truth has ministered and will ever minister to the intellectual life of men.

The view which I have thus inadequately set forth, though it runs counter to the familiar uses that men see in mathematics, is not new. I think it is foreshadowed in the fine phrase attributed to the Pythagoreans that mathematics is "the purifier of the reasonable soul." What else is the meaning of Plato's "God geometrizes continually"? Goethe must have had the same idea in mind when he pronounced mathematics the "fountain of all thought," and Novalis etherealized it when he called mathematics "the life supreme" and mathematicians "divine messengers." Schellbach said "Who knows not mathematics . . . dies without knowing truth."

In conclusion and for the purpose of reinforcing the view of the chief mission of mathematics which I have attempted to set forth I will quote a paragraph from Keyser's "Universe and Beyond."

> The domain of mathematics is the sole domain of certainty. There and there alone prevail the standards by which every hypothesis respecting the external universe and all observations and all experiment must finally be judged. It is the realm to which all speculation and all thought must repair for chastening and sanitation—the court of last resort, I say it reverently, for all intellection whatsoever, whether of demon or man or deity.

THE "NITROGEN CYCLE" IN EDUCATION

By Dr. WILLIAM H. STONE
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ONE of our commonest figures of speech makes oxygen the "breath of life." Comparable figures might identify other elements as equally indispensable to existence. Nitrogen in the tissues of the body is as necessary to life as is oxygen in the lungs. The influence of the latter is immediate and direct, however; of the former, indirect and relatively remote. Hence, the importance of the flame over the frame and the fuel has been a matter of common misunderstanding.

Always, of course, there has been a felt need for strengthening and energizing foods, instinctive to all animal existence, including man. Nitrogenous foods have always been sought, first under the native animal urge for survival, and later upon the empirical principle of observed results—for primitive societies are nothing if not pragmatic. But only in relatively modern time has scientific study and description rationalized the universal continuous demand for both oxygen and nitrogen in physical functioning.

It is axiomatic that knowledge of the indirect and remote, like wisdom, lingers. So that, although nitrogen was discovered as an atmospheric element a few years prior to the isolation of oxygen (both coming within the half-decade between 1770–75), the discovery of their true relationship to life was naturally reversed in time. Command and effect of oxygen being direct and immediate, its importance was patent. Not so with nitrogen, however. While, on the average, slightly more than three fourths of the volume of the air we breathe is nitrogen (as compared with but one fifth of oxygen), no direct or immediate interaction between this dominant gas and the body is observable—for the simple reason that it does not exist in any major functioning. The body, which can not subsist without nitrogen, is always immersed in that indispensable gas, breathes and bathes in it continuously; yet is impotent directly to make use of the precious element. For nitrogen is an "inert" gas, as directly unable to take its indispensable place in physical form or functioning as the body is helpless directly to utilize it. Hence, general knowledge of its circuitous ways into the body's multiplicity of cells has been relatively tardy.

Understanding of this devious path of "free" nitrogen from the atmosphere to usable compounds in the body tissues has taken the scientist afield with the humble husbandman. As far back as agriculture existed, undoubtedly, tillers of the soil knew that certain plants (now known as "legumes") were foods of remarkable potency. That was obvious, and simple. But they observed, also, a fact of much mystery, *viz.*, that these same plants instead of exhausting the soil actually enriched the ground from which they drew their substance. Here was one of various matters which smacked of magic; yet a fact established empirically, hence religiously utilized. So it came about that in the times when Asiatic fig growers were mystically hanging cuttings of branches from certain trees among the branches of other trees in order to insure a yield, Roman farmers, and doubtlessly grain husband-

men throughout the earth, were practising the magic of seeding their poorer soils to certain plants (leguminous) in order to enrich them while at the same time deriving from them valuable crops —albeit the Roman custom lacked in sedulousness in later times, if we are to accept the explanation advanced by Lucretius for the fall of the Empire. It remained for modern science to resolve these and many similar riddles of nature. For science, which develops formulae to support or destroy empirical conclusions, has written a simple explanation of the seeming magic of the legumes as one stage or factor in the "Nitrogen Cycle."

The leguminous plants, chiefly clovers, supplemented by peas, beans, etc., in minor rôles, are hosts to bacteria which possess the power denied to man, of transforming or fixating free nitrogen from the air into usable soil compounds available for plants, thence for animal utilizations fundamental to existence. Thus plant life, of specific varieties, constitutes a necessary link between the animal body and its indispensable nitrogen element. Animal life (upon major scale) possesses no such power. True, human intelligence has discovered certain limited sources of nitrogen compounds, and human ingenuity has devised chemical-mechanical means for manufacturing (fixating) usable nitrogen from the air; but neither our Chiles nor our Muscle Shoals may ever meet plant and animal needs for this basic life element without the major service of the legumes.

But the nitrogen cycle in soil fertilization and in maintenance of all animal life is now generally understood. Detailed exposition of the phenomenon is not necessary; hence, the foregoing brief statement of its significance is sufficient to serve the present purpose—which is to point out a parallel in the field of education, and one not so generally understood or appreciated. For the educational field, like the agricultural, must have its "legumes" through which to establish a "nitrogen cycle" indispensable to the spiritual life. Spiritually, man lives within an atmosphere of inert element, indispensable to the good life, but "free," impossible of direct utilization. Spiritual principles or precepts, ideals—the multitude of virtuous abstractions—these constitute the free nitrogen, the inert element of our educational atmosphere. Without them, "being" atrophies, is impotent for growth of good; character becomes a sterile soil productive of nothing better than good intentions.

Just as in the case of free nitrogen in the physical world, one may bathe in and breathe idealistic abstractions and still be barren of positive virtue. For the good life is neither understanding nor feeling, important as these are, but *doing*, the sum total of customary behavior—habit. It follows that right principles affect life only as they find fixation in the soil of constructive human experience. To become effective they must be lived, cumulated in the nodules of desirable neural patterns. Here they constitute a soil enrichment from which spring bountiful harvests of personal-social behavior.

In discovering and consciously employing this "nitrogen cycle" in development of social intelligence, scientific education has been much less progressive than has scientific agriculture. The psychologist has been slow to follow the path marked out by the soil chemist. For, while agriculturists have for centuries recognized their dependence upon the legumes of the nitrogen cycle in maintaining soil fertility, as the indispensable basis of all plant productivity, educationists have gone on fatuously faithful in the expectation that virtue might be absorbed as emotionality if not directly assimilated as understanding.

Hence, social intelligence has been sought as a response to emotional harangue and platitudinous moralizing. And during this time America has been strengthening her hold upon the unenviable reputation of being the least law-abiding country upon the face of the earth! All that we have achieved of individual and national character has been a by-product of pragmatically controlled living rather than a result of abstract vaporizing through which, chiefly, it has been sought. Only recently and then reluctantly are educators relinquishing the hope of inculcating virtue as knowledge or feeling. Only the accumulated teachings of "habit psychology" are checking the earlier waste of breath in academic incantation—are bringing the conviction that morality, civiculture, ethics, religion (whether the religion of emotionality and fear or the religion of rationality towards which we are trending), that, in fact, no single personal-social virtue may become effective unless fixated in the soil of customary behavior. Finally, however, the educator has discovered that just as it is impossible for the body to abstract directly from the air its necessary store of nitrogen, so is it impossible for the non-material being to draw directly from the atmosphere of academic abstractions the store of social intelligence indispensable to the good life. In the former case, man has learned to rely upon nitrogenous foods made possible by nitrogen fixating plants; in the latter case, he is learning to look to habituation made possible by types of education effective in fixating knowledge and feeling into the fertile loam of behavior.

Having finally found the scientific formula for development of the social intelligence, the alert educator has been quick to recognize the media necessary to its application; has identified the "legumes" of the educational field as the so-called "practical phases" of learning. Evidence of this is preponderant in the multiplying of "activity" curricula, the tendency, indeed, to "practicalize" all education by motivating it as natural outgrowths of native tendencies to investigate, to manipulate, to construct; by activating it as repeated response to life-like situations—by fixating the abstract facts of human aspirations into the living truths of human achievements through pleasurable participation in controlled social situations. To-day only a comparatively small and dwindling band of die-hards are clinging blindly to an outgrown philosophy of culture and to a worn-out psychology of disciplinary magic, traditionally ascribed to ancient times and civilizations long dead, as content and method best suited to assure a social intelligence compatible with modern industrial America. An equestrian coat of mail for Mr. Coolidge's mechanical hobby-horse! Within a few years these atavistic advocates will be as rare as are now those who forego strengthening, energizing foods for a more direct extraction of their necessary nitrogen from the atmosphere. The "end of the Middle Ages," foretold by Durant in commenting upon the passing of Santayana, is at hand; "hereafter it is America and not Europe that will write America's philosophies"—including her psychology of learning. Already the Americanization of William James and John Dewey has brought our educational philosophy, both as to end and means, "down from the clouds to deal with the affairs of men." Natural (unbossed) activity, motivated participation in socially desirable "affairs of men" is rapidly becoming the recognized end and way of all modern education, from kindergarten to college.

What the agricultural legumes—clovers, peas, beans, etc.—are in the

nitrogen cycle of the physical life, so are the educational legumes—the industrial, commercial, household and other practical arts—to the growth and maintenance of the spiritual life. As content, they supply to childhood and youth a bountiful harvest of basic social-economic understandings and fundamental skills —as essential to social adaptation as the mother tongue. Among these practical arts, the industrial are dominant, for the simple reason that America is dominantly industrial. The first requisite towards effective citizenship is all-round industrial intelligence—elementary understandings, appreciations, and control of the simplest mechanisms which, in their fullest development, are characteristic of that intensely industrial democracy which is America. These fundamentals constitute the content of the practical arts—immediate "food values" of these "legumes."

But as method they are equally important. For, like the legumes, while they supply directly a valuable harvest, also they enrich the soil in which they grow, with their wealth of actual or life-like situations, in interaction with which children and youth crystallize desirable habits of living. Thus they motivate, they activate, they integrate learning through social participation—in short, they fixate the free element of virtuous abstractions into personal-social habituations which in sum total constitute the worthy spiritual life.

SCIENTIFIC FANTASIES

By Professor D. W. HERING
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Is science out of place in the realm of fancy or fancy in the realm of science? It is the poet's privilege to soar upon clouds of idealism; is it not the métier of the scientist to attend strictly to material affairs and serve the arts of commerce and industry? That idea is widespread: let the shoemaker stick to his last—although it is on record that a shoemaker, one William Carey, managed to make a deep spiritual impression upon the world. The scientist is supposed to be a prosaic sort of individual who devotes himself so completely to facts that he must beware of displaying a lively imagination. Not that he would amount to anything if he were devoid of imagination—he is no true scientist if he does not possess this dangerous treasure—but it should be kept in the background. Enthusiasm that would excite admiration if directed to sports or business would rather disqualify a professional scientist hoping for the approval and support of the man of affairs. There may be occasions in which he can use his enthusiasm to inspire others, but, for the most part, he would better keep this (like other stimulants) for home consumption. He should not let it become conspicuous. In popular estimation, if he is suspected of such a failing, he is distrusted. The busy world is practical and the practical man has little sympathy with anything that smacks of the visionary. Impatient to discover the "practical" value of an idea, he asks "What has this work-a-day world to do with fantasies?" Well, it has more to do with them (or they with it) than is commonly supposed; for fantasies, even scientific ones, are not all harebrained. What with the achievements of science popularized and exploited in "Creative" this, "Marvels of" that, the other "In Industry," and the "Boy's Book" of them all, entertainingly written and richly illustrated, the impression is produced that the only merit and almost the only interest in science lies in its application to industrial and commercial pursuits. If the writers of these fascinating dramas of discovery and invention give a glamor of romance to the careers of the actors in them, it is usually a romance that reaches its climax in immense industrial works or colossal fortunes attained after early struggles and disappointments. Therein, apparently, lies the only excuse for science and scientists, and the stories are of a nature to emphasize this misconception of science, whether they are meant to do so or not. They are buttressed by columns of figures—correct, perhaps, but leaning like Pisa's Tower—and the pen pictures are drawn in grotesque perspective. The reaction to this of a person who is not disposed to deify trade or manufacturing is to look upon science as at bottom prosaic if not actually sordid, and all that is not materialistic in him is repelled rather than attracted by it; and, moreover, it leads him to put an unfortunate construction on that magic word "success." We hear of art for art's sake, and we are taught to scorn the spirit of the miser who accumulates money for money's sake, but we do not hear enough of science for the sake of science. The traits that inspired Galileo, Newton, Faraday, Bunsen, Kelvin, Pasteur and many other heroes who refused to capitalize their genius in cash or securities or to surrender to the promise of great wealth their devotion to science for its

own sake, are obscured by the glare of commercial aggrandizement. To the credit of modern industry be it said, however, that its captains to-day have gone far in the recognition of the material advantage to be derived from pure science and now foster it to an extent and in ways which they would have disdained a half century ago. Perhaps we shall learn that scientific endeavors may be fruitful and may teach wholesome lessons without regard to so-called "utilities." Initial success in a small way does lead to commercial development and this, in turn, supplies the means and the incentive to further scientific research, but it is the scientific enthusiast, not the profit seeker, who sets the ball rolling and overcomes the early difficulties and disappointments. Capital is too sensitive and too cautious to venture upon an enterprise before it sees a good prospect of financial return.

Since fantasies may be wildly speculative and in no case need be conclusive, the scribe who writes of them may take comfort from the thought that he can not be held responsible for the truth or the want of it which they may display; nor is he under any obligation either to maintain or to refute them. In his most irresponsible mood, however, it is a satisfaction to him to perceive how intimately many a fantasy, with its contradictions and extravagances, is associated with sober human experience—a satisfaction that will stay with him so long as he remembers that the uncertain ideas and unstable conditions may be only fantasies. We have been reminded repeatedly that the profoundest reflections of the natural philosopher—ideas that have led to the ocean cable, the electric dynamo or the airplane—have never lacked a romantic element, and our pleasure in the thought rises as we realize that this is as true to-day as it ever was. No fantasies in science? That is an unfortunate misapprehension; scientists themselves protest against it but with not much success. Aladdin and his lamp, the magic carpet, Sindbad and other stories from the Arabian Nights; imaginative strivings of medieval gropers or dreamers; searchings of the heavens by Galileo or Kepler; speculations of spiritualists; were not more distinctly fantasies than the present-day probings and daring hypotheses that are opening the inner recesses of Dame Nature's sanctum; and these must be always of the nature of fantasies until prolonged experience brings them out of the clouds and places them upon a solid footing. Sometimes, it is true, they prove to be mists that are soon dispersed, but even these are interesting while they last. When the morning newspaper brings us the announcement of some new achievement or discovery, as morning newspapers have fallen into the habit of doing, our wonder and admiration are concentrated upon the thing itself; not until long afterwards, perhaps when claims of priority are under discussion or litigation arises over "rights," do we appreciate the work of imagination that culminated in a great realism—mental pictures, cogitations, plans, a system of arteries and veins that distributed the life blood upon which the scheme lived and grew and matured. Assuredly, not all grow up; many never come to light, and among the waifs and strays of mental progeny are lame and misshapen figures, the outcome of ill-conceived or misdirected fantasies. Induction is not sufficient. Groping after clues, speculation as to how to account for new phenomena, has compelled scientists boldly and violently to burst the trammels of what had seemed to be laws that proved inadequate to new discoveries, and each discovery but adds new perplexities. For example, the line spectra of elements, in their simple form long a powerful means of analysis along narrow separate paths, have become a wilderness; energy in *quanta* instead of continuous flow brings out new relations

(or new explanations) of matter, energy, electricity, light—in short, the constitution of the universe. It was a poet of the seventeenth century who used the startling figure of "the wrecks of matter and the crush of worlds," it is the physicist and chemist of the twentieth who pictures to us the shattering of the atom and the construction of a world. It is only ignorance that fails to see in the scientist the richest faculty of imagination, and it is a mistake to think that he deals only with assured facts; he dreams dreams and sees visions, not at all to his discredit if he is not thrown off his balance by them. Although the truth is his goal ultimately, his fancies make the path to the goal sometimes flowery even if the facts are thorny. A difference—perhaps the most significant one—is that whereas the fantasies of a story-teller are likely to be woven when the author is in a dreamy state, with eyes closed, those of science are the product of a weaver whose eyes are open and who is very wide-awake.

Has art staged anything more dramatic than the following sequence of events? The first conversation by Dr. Alexander Graham Bell over the telephone was on March 10, 1876, from his workroom upstairs to the cellar; electric waves from a spark discharge, foreshadowed in the work of Faraday and forecast by Maxwell, were first detected by Dr. Heinrich Hertz in 1887. These were strictly laboratory performances; both events were like newborn infants and required careful, skilful nursing and, like the often cited baby, were of doubtful use. On March 7 ,1926, fifty years lacking just three days after Dr. Bell's success and not quite forty years after that of Professor Hertz, conversation was carried on between New York and London for several hours, broadcast in electric waves and heard by telephone! Professor Hertz had died thirty-two years before this, and Dr. Bell as many months, but the work of these pioneers had been pushed by others no less devoted to it. Scientists were not so dull as to be unaware of the commercial importance of their discoveries, but the great possibilities of financial gain contributed very little to the thrill that came, on these several occasions, to the men whose genius brought about this astounding dénouement. Fantasies? We are not to suppose that final results (if the results are final) are exactly like the image the worker had in mind in the beginning, but from the beginning he envisages something not perceived by the unimaginative; sights unseen, flights unflown, creations unformed—meaningless to the stolid brain—are real and vivid to the artist, whether he works with brush, with chisel, with pen or with the tools of the laboratory. That is just the difference between the artist and the artisan; one walks by faith and the other by sight. The situation of the imaginative scientist is not unlike that of Michelangelo who saw the figure imprisoned in the block of marble and could not rest until he had set it free. Of such a scientist it has been said, "He is glad if his discoveries can contribute to man's economic welfare and material comfort, but he believes that the chief contributions of science to civilization are its effects on thought and conduct."[1] He is exultant when his discovery is harnessed, but it is very discouraging to be called on to prove the "use" of a recondite idea in advance. What the scientific devotee wants to do is to advance science beyond its known applications and let it find its field of operation for itself; it is quite sure to do that, it runs no risk, there is no manner of doubt that it will prove of service eventually; to-day the highest tributes of praise are being paid to the greatest genius, the most widely distinguished and the least known of American scientists, Josiah Willard Gibbs.

[1] Professor E. P. Lewis, *The University of California Chronicle*, July, 1925.

SCIENCE IN RUSSIA TO-DAY

By Professor WILLIAM SEIFRIZ

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RUSSIA, for many of us, is a vast expanse of territory extending from eastern Europe to China; a land covered with snow the greater part of the year and traversed only by sleighs, drawn by horses with queer wooden yokes and followed by wolves; a country notorious for its cold, desolation, czars and prisoners of exile. To be sure, we have heard of large cities, such as St. Petersburg and Moscow, but these heighten rather than soften the awe-inspiring picture which Russia presents, for in St. Petersburg have lived the czars in whose names awful things have been done, and Moscow conjures up in our minds the vision of a starving and retreating army. Recent events have added to the tragedy of Russian history. Revolution has recurred with an intensity and an after-effect surpassing all previous outbreaks, and stories of great suffering and sacrifice have been told us.

It is only natural that our opinion of science in Russia to-day should fit in with our conception of Russia as a whole. It is reasonable to believe that Russian science has suffered the same vicissitudes as have the government and the people. To a degree this is true, but much less so than is generally appreciated. The doubts which have been expressed on both the quantity and the quality of Russian science are as ridiculous as were the similar doubts expressed on German science during the great war. We heard that the science of the Germans was not to be trusted since it was all done with but one motive, the glory of the Vaterland. One wonders if Strasburger had the Vaterland in mind when he had a large oak tree held upright while it was cut at the base and transferred bodily to a vat of staining solution to determine the path of ascending sap, or that Fischer was solely interested in increasing the power of the German empire when he succeeded in synthesizing sugars, or that Pfeffer thought his measurements on osmosis would enhance the chances of success of Germany in the next war. These same jealous haters of humanity are to-day the enemies of Russia. Just such statements as were made of German science during the war are now applied in an altered form to Russian science. "Why go to Russia? Nothing is being done there. No one can possibly work under present conditions. The Soviet Government has no interest in science, art or any intellectual activity." The truth, and some there is, which exists in these statements, is slight. It is my purpose here to present quite a different picture of science in Russia to-day. In so doing I in no way wish to convey the impression that our comrades in Russia have not lived through most trying times—they have, and I shall refer to their suffering—and I do not forget that many of our colleagues have gone to other lands or to another world, and that those still remaining are working under a great handicap; nor do I wish to justify the existence of the present régime in Russia (any more than I should care to seek some ground upon which to justify the existence of the old government). It is my intention simply to state precisely what I saw and heard in the land of the Russians, and if I glorify science in Russia to-day it is solely because of the quality of the work and the courage and fortitude with which it has been done.

VOSKRESSENIE NA KROVI
ALEXANDER II WAS ASSASSINATED ON THAT PART OF THE WALK TO THE LEFT, NEAR THE IRON RAILING, WHICH IS NOW ENCLOSED WITHIN THE CHURCH BUILT IN HIS HONOR.

There has been no cessation of scientific research in Russia either during the war or after it. While the war was on, some, the botanists, for example, found it more advantageous to continue work in an isolated place such as Tiflis—and what botanist would not seize with delight the opportunity to study the flora of the Caucasus. But whether in far Georgia or still in the home laboratories at St. Petersburg or Moscow, research continued throughout the war. Then came the trying years of 1918 to 1921 when the college professor and his wife stood shoulder to shoulder with the street laborer in line for hours waiting for their apportionment of bread and fish. Still research went on.

The graph at the national herbarium shows a gradual decrease in the number of plants added until 1920. The previous year, 1919, saw the low ebb of the revolutionary tide. The winter was extraordinarily severe. The old and the weak succumbed. Food was sufficient only, as my Russian friends expressed it, "for healthy people not to die." Teaching and research still continued but in classrooms and laboratories where the temperature fell below 0° C.

Since 1920 scientific activity in Russia has been steadily on the upward trend. The herbarium chart again illustrates this. The curve indicating the number of specimens added annually to the national plant collection goes rapidly upward from 4,000 in 1920 to 6,000 in the next year, then to 36,751 in 1925; 60,968 in 1926; and 90,650 in 1927.

The two factors responsible for the

THE HOUSE OF SCIENTISTS IN LENINGRAD
FORMERLY THE PALACE OF GRAND DUKE VLADIMIR, UNCLE OF THE CZAR, AND NOW A DORMITORY FOR VISITING SCIENTISTS

success of Russian science during the last ten years has been the superb spirit of our colleagues there and the excellent support which the communistic government has given them. To those of us who have heeded foreign propaganda—and there is no information which is more maliciously untrue than war-time propaganda—it is a great surprise to learn that the Bolsheviks have encouraged science and art as far as it has been financially possible for them to do. I had heard that the superb collection of paintings in the Hermitage had been pillaged, yet I found this gallery of art complete and well cared for. Some private collections have, to be sure, been lost or destroyed, but the national galleries are intact. I might here add that if an excuse to visit Russia is sought, the collection of paintings in the Hermitage and in the National Gallery of Russian art, formerly the gallery of Alexander III, would justify any one for making the journey to Leningrad. It may be nothing short of sacrilege to say so, but these two galleries combined surpass, in painting, even that mother of all art collections, the Louvre.

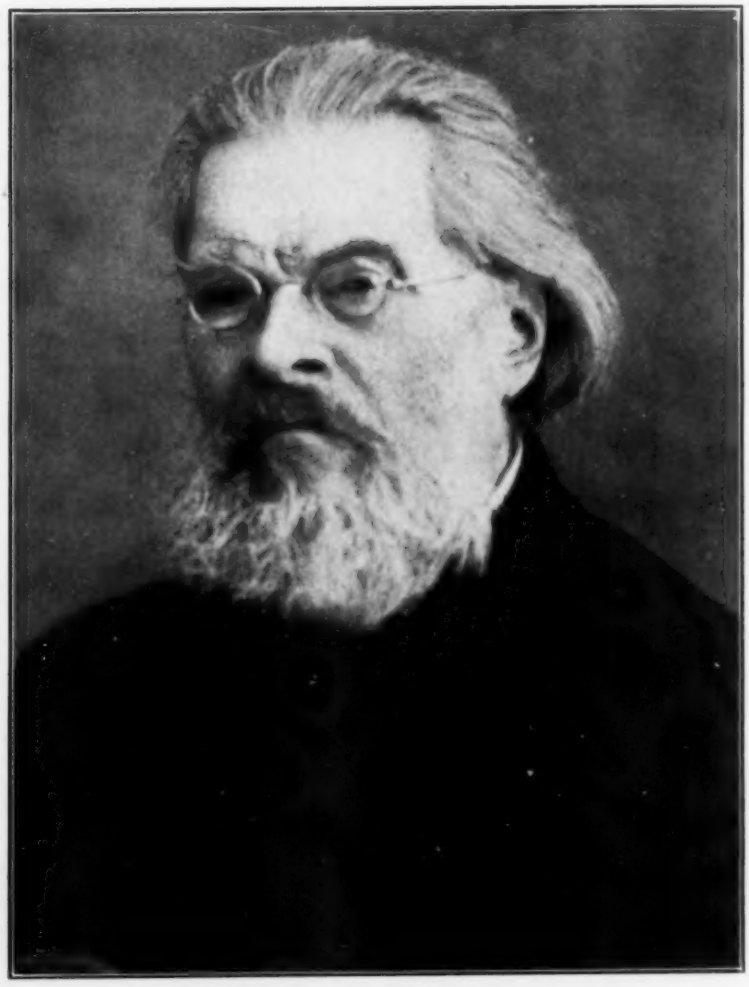
I had also heard that religious worship was prohibited, that all priests had been exiled or executed, and the churches destroyed or converted into schools. Great, therefore, was my surprise when I heard church bells ringing on my first morning in Leningrad; and I later found the little cathedral well filled at mass. The particular church in question is the jewel of all houses of worship in Russia, not in historic value, but in Byzantine splendor of form and color. It is the church "Voskressenie na Krovi," literally "Resurrection on Blood," the blood being that of Alexander II, who was assassinated here in 1881, the cathedral having been built around the spot where he fell. Religious worship is not a part of the communistic creed, but the government permits it. Indeed, to rob the Russians of their religion would be impossible. Religion forms a more intimate part of the lives of the Russians than any other Christian people.

While the Soviet government does not support religious worship, yet it has preserved and cared for all objects of a religious nature where these are of historic or artistic value. But it is the government's support of science in which we are primarily interested.

The first proof which I had that all activities in Russia, academic as well as political and commercial, are under government control and support was the "House of Scientists" to which I was escorted on my arrival and which remained my resting place at night during my sojourn in Leningrad. This building was the former palace of the Grand Duke Vladimir, uncle of the Czar. The house is now a dormitory for visiting scientists. My room was the library and commanded an impressive view across the Neva river with the Peter-Paul fortress—the bastille of Russia—just opposite. Over my cot hung a portrait of Lenin and in the corner stood two red banners. The palace has been pretty well stripped of its valuable furnishings, but its architectural beauty remains. Especially fine is the stairway leading to the grand ball room.

Among the world-renowned treasures of Leningrad is the Botanic Garden with its mile of greenhouses and its herbarium of 3,000,000 specimens which represent 95 per cent. of the world's species of plants. This collection closely approaches, and in certain groups surpasses, in number the famous collections of Kew and Berlin. Professor Issachenko is director of the Gardens.

At the university, the botanical laboratories compare well, both in size and the amount of work being done there, with those of any other institute of learning; indeed, the department of botany at the University of Leningrad surpasses those of some of our leading American univer-



PROFESSOR IVAN P. BORODIN
DEAN AMONG RUSSIAN BOTANISTS

sities. This fact leads me to venture a remark about botany departments in general.

A visiting Swiss scientist recently had pointed out to him the botany building on the campus of one of our American universities.

"Yes," said our guest, "I should have known that that was the botany building without your having told me."

"But how?" we inquired.

"Because it is the oldest building I can see anywhere."

When then asked why it was that the botany department of most colleges is usually shoved into a corner, as exemplified in several leading universities of this country, the Swiss answered the question by saying, "Because we botanists won't fight." Was this the confession of a fault or a virtue? Farlow once expressed a phase of this situation in a humorous way when he gave the following opinion of a just published textbook of biology, "Well, the book seems to me to be mostly about the lobster with not enough lettuce in it to make a decent biological salad."

Among Leningrad men of science those who stand out as preeminent are Pavlov in human physiology, Karpinski in geology, Borodin in botany, Vavilov in genetics, and Maximow and Kostychev in plant physiology. The veterans of this group are Karpinski and Borodin.

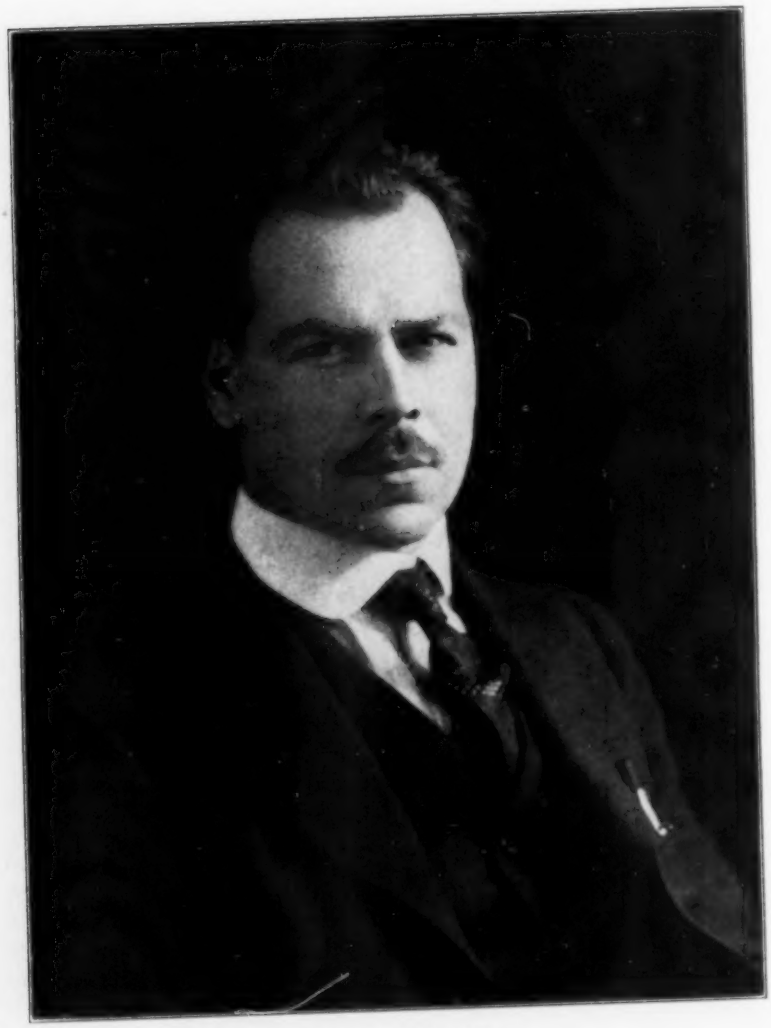
The grand old man of academic botany in Russia is Professor Ivan Borodin. While no longer engaged in university work he is, at the age of eighty-four, still very active mentally. It is a joy to meet him, to join in his good humor and to hear his animated conversation. The events of the last ten years have not in the least broken his spirit. When I asked of others just what position he held among Russian botanists, I was told that, "what Coulter is for America, Borodin is for Russia."

While at the university one should not fail to visit the most sacred room of this time-honored institution, the laboratory of Mendeléeff.

When the prejudices and petty jealousies of those who are living irritate and sadden us, and the joy of work is lessened, the best restorer of our waning enthusiasm is a pilgrimage to the homes and the workshops of the masters who have gone before. Standing in the shadow of their greatness we forget our little difficulties and remember only how fine a thing it is to have added to the advancement of science.

There is no better way to become acquainted with a people than to mingle with the younger generation. Adults, especially if life has handled them severely, soon acquire a crusty exterior which permits little of this real character to seep through. Children, on the other hand, are like books and reveal their true inner selves. One can, therefore, never say that one knows a country unless one has mingled with the younger folks.

University students in Russia seem to be in a state of perpetual good humor, a fact one constantly marvels at when realizing how little they have of even the necessities of life. Poor clothing, simple food and painfully plain living have not dampened their spirits nor made them ill-humored. The gracious attitude which Russian students assume in the presence of a stranger delightfully illustrates one of the outstanding traits in Russians, courtesy to a visitor, a trait which one would like to see many another European people emulate! I was introduced as a professor from the United States who had come to far-off Russia to see how Russian students compared with his own. The girls and the young men instantly arose to their feet, smiled and bowed and expressed the hope that I would judge them kindly, adding that they were undoubtedly not as well clad as American students nor as bright, but that perhaps they did not compare very unfavorably.



DR. N. J. VAVILOV

GENETICIST, DIRECTOR OF THE INSTITUTE OF APPLIED BOTANY

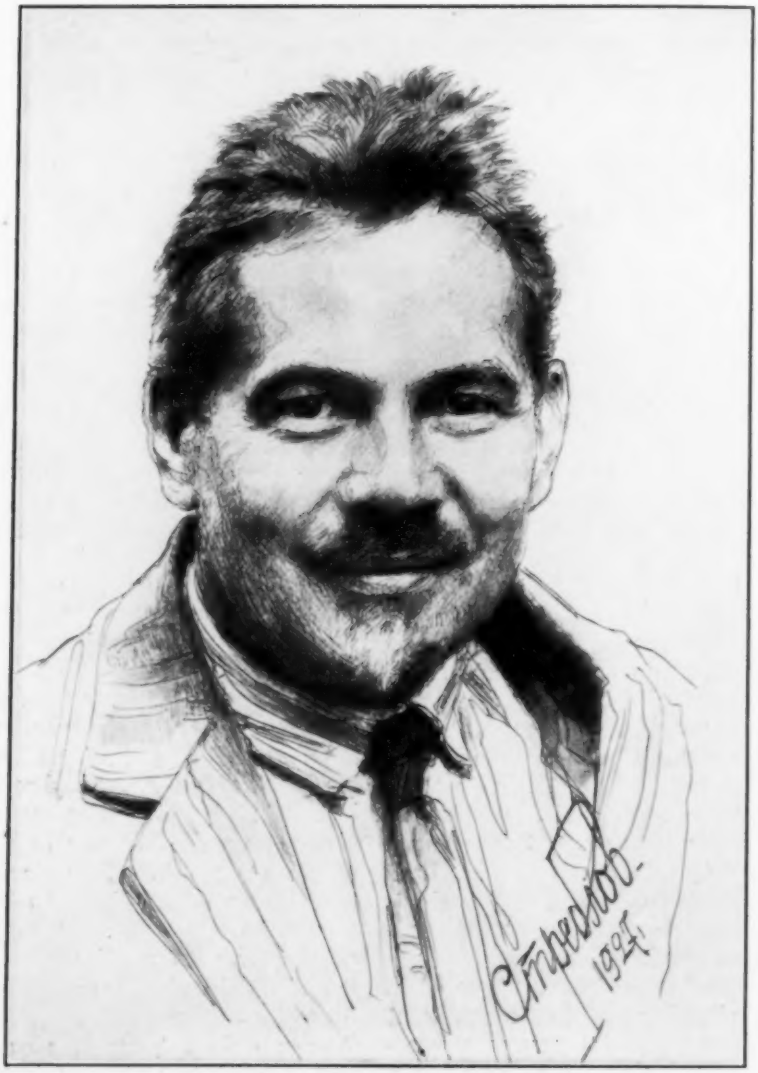
Another charming feature of student life in Russia is the somewhat intimate and affectionate relationship which exists between student and professor as illustrated in the custom of calling the professor not by the usual formal title of "Professor" prefixed to his last name, but by his two first names, "Nicolai Alexandrovitch" (Nicholas the son of Alexander).

Research in botany, agriculture and plant breeding exceeds that of the other sciences in Russia since the nation's present problems are primarily ones of food. The same emphasis is laid upon industrial rather than theoretical research, in chemistry for example, as we shall see in Moscow. Yet pure science is keenly pursued by a smaller though active and capable group of men.

The foremost organization in Russia devoted solely to research in the botanical sciences is the Institute of Applied Botany, with its central office in Leningrad and its chief experimental laboratories at Detskoje Selo. The latter is a little village near Leningrad which formerly bore the name of Tsarskoje Selo. It was the summer home of the last Czar, and also of the great Katherine, and of Paul I. To depart again from science for a moment let me remark that the palace of Katherine II at Detskoje Selo is exquisite, surpassing that of Maria Theresa at Schönbrunn, and equalling, if it does not in sheer beauty surpass the palaces of Versailles. What a contrast exists between the royal splendor and artistically planned palace of Katherine II, at Detskoje Selo, with its room of amber walls, its magnificent parquet floors, and its general appearance of refined elegance so befitting a queen, and the bourgeois mid-Victorian decorations devoid of intellectual interest or esthetic taste in the palace of the last Czar, where the walls of the Czarina's bedroom are covered with cheap trinkets of the church, and her sitting-room literally bespattered with the contents of certainly not less than six family albums! Throughout the visit to the summer palace of Nicholas II but two sympathetic notes are struck—and these are more of pity than aught else—one when viewing the photograph of the sweet face of the Czarevitch, and the other when seeing on the Czar's calendar the last sheet which he touched, July 31, 1917, the night when he and his family were hurried off to Siberia.

The scientific director of the Institute of Applied Botany is the energetic Vavilov whose own particular field of research is genetics and plant breeding. Vavilov is a man of extraordinary activity and enthusiasm which he instills into all who are associated with him. Codirector with Vavilov is the communist Kogan (Russian for Cohen). All government institutions have two directors, one in charge of technical work and one in charge of the government's interests, and in all instances where I made definite inquiry, I was informed that the communistic director in no way hampered or interfered with the proper functioning of the scientific activities of the institution.

Most interesting experimental research is being done by the department of applied physiology, of which Professor Nicholas Maximow is director. He is assisted by Mrs. Maximow, who is also professor of botany at the school of pharmacy. The laboratories of the department of applied physiology are at Detskoje Selo housed in the villa of the Grand Duke Boris, which was erected for him by his godmother, Queen Victoria. The boudoir table in the former duke's home is now a chemical hood, his bureau has been converted into a laboratory table, and the billiard table is being used for sorting and counting seeds from experiments in genetics. It was perhaps a little severe on the duke to have put him out of house and home and country, if indeed his life has not been sacrificed,



PROFESSOR NICHOLAS A. MAXIMOW

DIRECTOR OF THE DEPARTMENT OF APPLIED PHYSIOLOGY AT LENINGRAD AND DETSKOJE SELO

yet one can not help but feel that his villa is serving a better purpose now. The Grand Duke Boris has a brother Cyril, who is now in Paris and is one of the pretenders to the Russian throne.

Among the outstanding experiments being carried on in the physiological laboratories at Detskoje Selo are those on the photoperiodism of plants, the equipment for which surpasses that of any other research institute except the Department of Agriculture in Washington. Of value also is the work being done on the physiology of root systems. The experiments are in charge of Mrs. Krassovsky.

Mrs. Maximow and Mrs. Krassovsky, both of whom are doing good scientific work, are examples of the prominent part which the women of Russia are playing in the affairs of their country. The communists believe in the equality of the sexes. The majority of women, married and unmarried, are employed. The customs official in charge of the border station at Ostrov is a woman. The chairman of the committee on foreign relations in Moscow is Trotsky's sister.

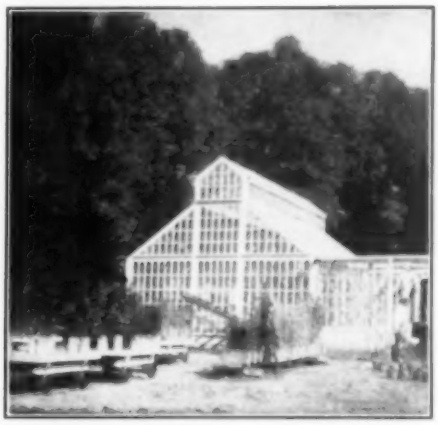
Another interesting experiment carried on at Detskoje Selo, by Dr. Karpechenko, is a successful cross between a radish and a cabbage. What the offspring are to be called has not yet been determined. Some of them have temporarily been given such awe-inspiring names as "hypohexaploid hybrid" (because they have fifty-one chromosomes, less than the basic number of nine). The progeny resemble the paternal side more than the maternal. The cross between *Raphanus sativus* and *Brassica oleracea* is about as wide a one as any yet recorded.

Among other scientists of note in Leningrad two stand out as preeminent among Russian scholars of to-day. These are the great Pavlov, widely known for his work on "conditional reflexes," and

THE EXPERIMENTAL PLOT OF RADISH × CABBAGE HYBRIDS OF THE SECOND GENERATION AT DETSKOJE SELO

MRS. N. A. MAXIMOW
PROFESSOR OF BOTANY AT THE SCHOOL OF PHARMACY, LENINGRAD

LABORATORY OF THE DEPARTMENT OF APPLIED PHYSIOLOGY AT DETSKOJE SELO
FORMERLY THE VILLA OF GRAND DUKE BORIS

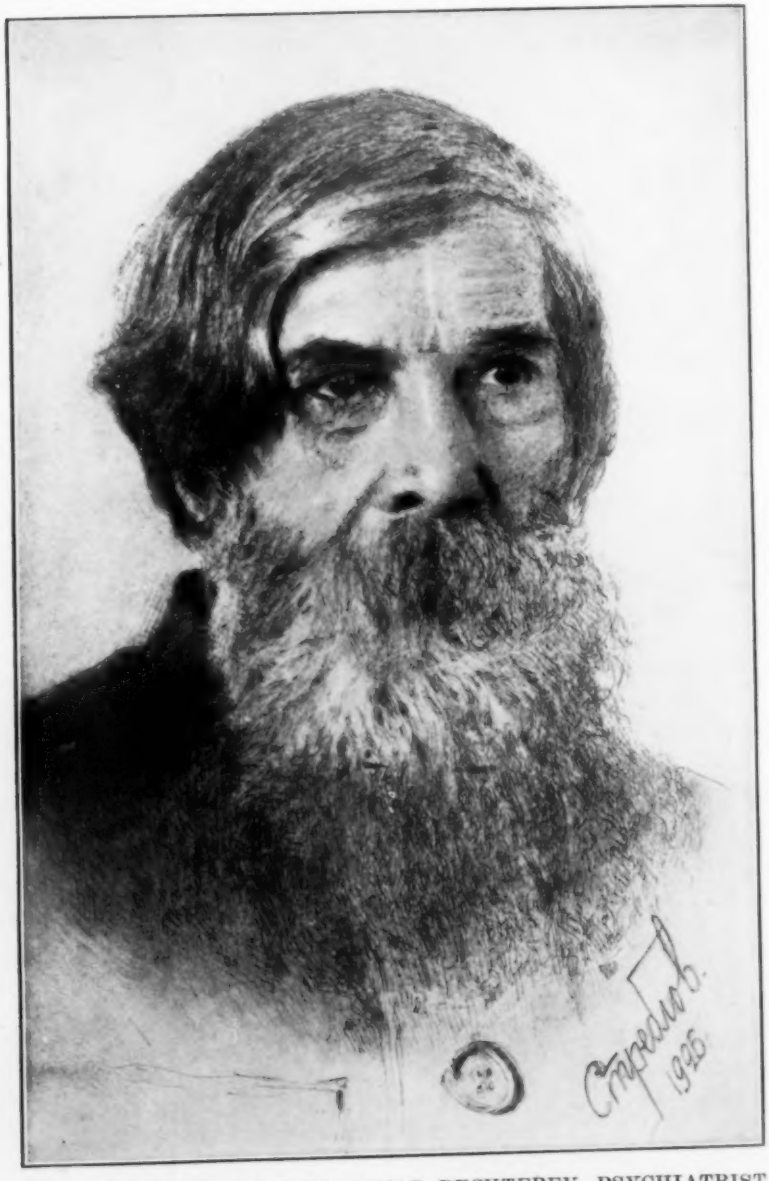


EQUIPMENT FOR EXPERIMENTS IN PHOTOPERIODISM AT DETSKOJE SELO

the geologist Karpinsky, president of the Academy of Sciences at the age of eighty-two years.

An interesting character among men of science is Kovalevsky, director of the Institute of Agronomy, who has the extraordinary distinction of being a highly honored employee of the Soviet government, even though formerly Minister of Finances of the Czar. The retention of Kovalevsky in a scientific position of importance is an example of the occasionally evident far-sightedness of the Bolsheviks, for which we must give them credit, whatever shortcomings they may have. They realize that a man like Kovalevsky is of value to the country, especially in so important an economic subject as agronomy, and they, therefore, retain

MRS. KRASSOVSKY AND HER ASSISTANT
AT WORK ON THE PHYSIOLOGY OF ROOT SYSTEMS



THE LATE PROFESSOR VLADIMAR BECHTEREV, PSYCHIATRIST

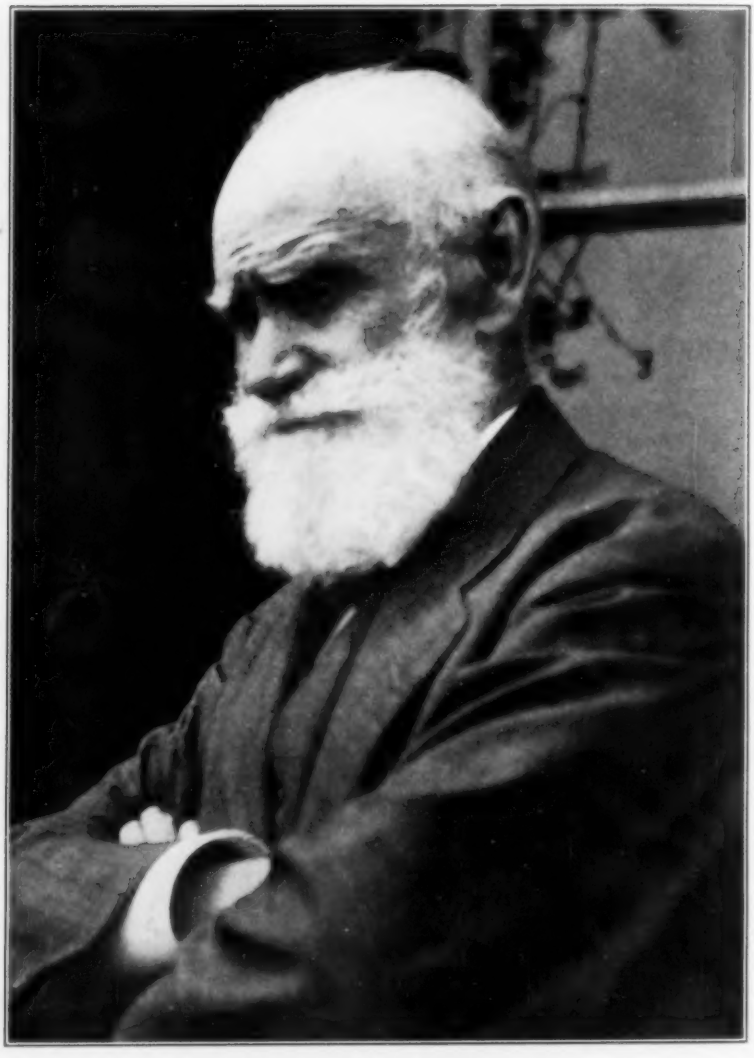
him even though he exemplifies the old aristocracy. Kovalevsky is, in his turn, discreet enough to devote his attention solely to matters of science. This policy of the present government is interestingly and somewhat amusingly shown in those cases where the government has confiscated private collections of old religious paintings, ancient manuscripts, and the like. Realizing that the former owners of these collections are the only ones capable of studying them and properly caring for them, the government has confiscated not only the collections but the owners as well, with the result that the latter still live with their treasures, but now as employees of the government!

Vladimar Bechterev, professor of psychiatry, is the last scientist of Leningrad to whom I wish to refer. Bechterev gained some notoriety of late from his plan to establish a "pantheon" or museum of brains of deceased Russian men of note. Only recently he, too, passed into the great beyond, having dedicated his brains to the museum which he established. I mention Bechterev not because of his scientific prestige but because of his physiognomy! I purchased Bechterev's portrait since he represented for me the storybook type of Russian whom one would expect to find seated in one of those sleighs racing across snow-covered Siberia followed by wolves to which I referred!

Though we are primarily interested in men of science it is only right that we stop a moment and praise the work of the eminent Russian artist whose portraits of Professor and Mrs. Maximow and of Bechterev we are producing. Streblow was a portrait painter of note during the régime of the last Czar, members of whose family he has done. While still the recognized leader in the art of portraiture, Streblow's social status has fallen to that of the proverbial, struggling art student. He is now obliged to do a dozen portraits a month in order to eke out a living whereas he formerly did one or two and lived well.

We have heard much in America of the underpaid college professor, of the lack on the part of the public of any great respect for or confidence in the university teacher, and of the relatively low social standing which the professor and his family occupy. It is therefore of vital interest to know that these conditions are in all respects reversed in Russia to-day. Those whose social status is the highest, those who are the best paid (with a few exceptions) and the most highly respected are the academicians. It is nothing short of a miracle, which only Russia could have accomplished, that has, literally over night, made the scientist the upper man of the community both in wealth and social standing. At the gala performance of the opening of the opera season in Leningrad the most distinguished person present was the geologist Karpinski.

For the first time in modern history the professor's salary is near the top. The young assistant-professor in Russia receives one hundred rubles ($50.00) a month. The under-official in the government receives not more than one hundred and twenty-five rubles a month. The full professor is paid some one hundred and fifty rubles a month. The highest salary of a valued director of research is four hundred rubles ($200.00) a month. The approximate maximum salary of any government position is six hundred rubles ($300.00), which is drawn only by those few who occupy the highest positions. The stenographer's salary is from eighty to one hundred and forty rubles. The lower incomes permit one individual to live without want. Where a man is married, his wife is either also employed or he holds teaching positions in two institutions. The higher salaries allow a fair degree of comfort. Luxuries, with the exception of the theater, without which no Russian can happily live, are seldom indulged in,



PROFESSOR IVAN P. PAVLOV
DIRECTOR OF THE INSTITUTE OF EXPERIMENTAL MEDICINE, LENINGRAD

and by luxuries I refer to a summer's vacation or a full-course dinner. Such extravagances are all but unheard of.

The student leads a life of extreme economy, yet he has not allowed his poverty to alter materially his naturally friendly and happy disposition.

The average student must exist on twenty rubles ($10.00) a month (paid by the government) and he does it in this way; three rubles a month for his room, which he shares with a comrade, supplying his own blankets and pillow; six kopeks (three cents) a day for one and one-half pounds of black bread for morning and night—the cost of tea to drink with the black bread can be spared, since there is, after all, no nourishment in tea, therefore, hot water will do just as well—twenty-five kopeks a day for half the cost of a fifty kopek dinner, the dinner to be shared with a comrade; three rubles a month for laundry and baths; this leaves less than five rubles a month for books, shoe-repair and theater. No item has been included for clothes. Few clothes are bought. Old ones are patched and repatched, but if money is needed for this purpose the student can earn it by extra work at the docks. If a student is missing from class no questions are asked, since it is taken for granted that he or she is at the docks. This poverty and deprivation is endured without complaint.

Before leaving Leningrad a brief visit should be paid to the National Library, where Dr. Rimsky-Korsakow will show us about. Dr. Rimsky-Korsakow is the son of the famous composer of the same name. The former Imperial Library in Leningrad is something more than a mere collection of books. There are many fine engravings, including a collection of portraits of Paul I, and some oil paintings, notably a large canvas of Katherine II. Especially fine are the old manuscripts and early editions of books, which include several very rare Bibles. These early editions are housed in a small room built after the manner of an imaginary studio of Faust which gives quite the appropriate atmosphere for ancient writings. This quaint room "à la Faust" is known as the Division of the "Incunables," namely, the division housing books edited not later than 1500. Among other treasures is the Gutenberg or Masarinov bible.

One leaves Leningrad with a new conception of Russia, for one has discovered art there which surpasses that of other world cities; palaces whose richness and beauty are not elsewhere to be found; library facilities the like of which few nations can boast; and an activity in scientific research that is extraordinary in the face of what Russia and her people have suffered.

The peaceful state of Leningrad belies all reports of the unsettled, lawless condition of the country. The city is as quiet and as orderly as one could desire. When one compares the village-like peace of Leningrad with the noises and horrors committed *and tolerated* in New York, Philadelphia and Chicago, one wonders if it is Russia or our own country which needs looking after the more.

Moscow and Leningrad differ in almost every conceivable respect. Leningrad is a quiet, conservative, residential city, dominated by the activities of men of science, letters and art, a new city famed for its institutions of learning, its collections of paintings and its palaces. Moscow is a noisy, progressive, commercial and political city, dominated by the activity of government officials and men of trade and commerce, an old city famed for its ancient walls and churches. There is considerable rivalry between the two cities, a Leningradian is unhappy in Moscow and never goes there unless he is forced to, while a Moscovian avoids Leningrad as a New Yorker does Philadelphia!

A similar marked difference in the type of scientific work done in the two cities is noticeable. Research in Moscow tends more toward the practical and commercial, in Leningrad more toward

the academic. We thus find in Moscow twenty institutions of industrial chemistry and technology out of a total of thirty in all Russia. It should not be assumed, however, that academic research work is at a standstill in Moscow. On the contrary, the department of botany at the university, where Professor Michael Golenkin is the senior member, is quite active. There is also the Timiriasev Federal Institute of Scientific Research, small to be sure, but having such eminent workers as the cytologist Nawashin and Professor Alexander Kiesel, whose work on the chemistry of protoplasm is the best yet done. More pretentious are the several institutes of biology and chemistry, of which Alexis Bach, best known for his work on oxidases, is director. These are the Karpow Chemical Institute, the Bach Biochemical Institute and the Institute of Experimental Biology.

At the first-mentioned institute of industrial chemistry every effort is being extended to make Russia independent of the world in her needs in technical products, thus, the research on dyestuff is especially active. An adjoining laboratory has succeeded in producing a bakelite which is said to be superior to the American product.

Moscow is a city half of the orient. Its ecclesiastical architecture is Byzantine, its people phlegmatic and its beggars classic. More picturesque mendicants are not to be seen anywhere, especially the street urchins—delightfully happy little rascals they are. When I objected that I did not have sufficient kopeks to divide among so many, one replied, "Oh, that is all right, we are working together!" But the story of these lawless ragamuffins is a tragic, not a happy one.

Intellectual activity in Russia, while centered in Leningrad and Moscow, is not restricted to these metropoles. Kiev, Charkov, Odessa, Rostov, Minsk, Perm, Tomsk, Vladivostok, Baku, Tiflis, Saratov, Kazan and several other cities, including far-off Tashkent, have their universities.

One can not visit the land of the Russians, accept the gracious hospitality of the people, share in the enthusiasm which they have in their scientific work and observe with what patience and good humor they bear their hardships, without departing with every feeling of sympathy and good will. There may exist differences of opinion on the advisability of our or any other country recognizing the Soviet Government, but the question whether American men of science should recognize their colleagues in Russia, and interest themselves in the needs of Russia science, has but one answer. To speak ill of Russia and the Russians is to speak in ignorance.

A STORY OF THE RISE OF A SOCIAL TABOO

By Professor KIMBALL YOUNG
UNIVERSITY OF WISCONSIN

I

To expose the origin of a social taboo is to reveal an important factor in social control. It is the purpose of this paper to trace the rise of a group taboo in a pioneer society in western America. The particular example will be that of the rise of the taboo on the killing of a gull among the Mormons in the early days of their settlement in Utah.

The first group of Mormons, 143 in number, arrived in the valley of the Great Salt Lake on July 24, 1847. Some small tracts of land were put under irrigation within a few weeks. Throughout the summer additional "companies" of pioneers arrived and before autumn considerable land was brought under cultivation. By the spring of 1848, the colony was fairly well established. Whitney, in his "History of Utah," describes the situation as follows:

> The opening of the spring of 1848 in Great Salt Lake City saw nearly seventeen hundred souls dwelling in upwards of four hundred log and adobe huts inside the "Old Fort." Over five thousand acres of land had been brought under cultivation, nearly nine hundred acres of which had been sown with winter wheat, the tender blades of which were now beginning to sprout.

Naturally the strain on the food supply had been very severe during the winter of 1847–1848 and the settlers were thoroughly dependent for survival upon the forthcoming harvest of 1848. Their remoteness from outside sources of food supply was obvious. And during the summer of 1848 hundreds more of Mormons arrived from the Missouri River region, which but added to the demands on the food resources for the coming winter.

In May and June of 1848 large numbers of crickets (*Anabrus simplex*) began to appear in the wheat fields. At first little attention was paid to these pests, but as time went on they increased in number and in the damage they did to the growing crops. Mr. Anson Call, one of the Utah pioneers, gives the following pious but amusing description of the insect:

> The Rocky Mountain Cricket, as now remembered, when full grown is about one-an-a-half inches in length, heavy and clumsy in its movements, with no better power of locomotion than hopping a foot or two at a time. It has an eagle-eyed, staring appearance, and suggests the idea that it may be the habitation of a vindictive little demon.

The crickets made another intense crisis for the already much harassed Mormons. Removed both by distance and by prejudice from assistance, the very existence of the group seemed at the time to be threatened. Every effort was made to drive off the pests. Whitney writes of the period:

> With the energy of desperation, the community, men, women and children, thoroughly alarmed, marshalled themselves to fight and if possible to repel the rapacious foe. While some went through the fields killing the crickets, and at the same time, alas! crushing much of the tender grain, others dug ditches around the farms, turned water into the ditches, and drove and drowned therein myriads of the black devourers. Others beat them back with clubs and brooms, or burned them in fires set in the fields. Still they could not prevail. Too much headway had been gained by the crickets before the gravity of the situation was discovered, and in spite of all that the settlers could do, their hopes of a harvest were vanishing, and with these hopes the very hope of life.

The pressure of hunger became very real. One of the settlers, Parley P.

Pratt, thus describes the hardship of his family:

> During this spring and summer my family and myself, in common with many of the camp, suffered much for want of food . . . We had lost nearly all our cows, and the few which were spared to us were dry . . . I had ploughed and subdued land to the amount of nearly forty acres . . . In this labor every woman and child in my family, so far as they were of sufficient age and strength, had joined to help me, and toiled incessantly in the field, suffering every hardship which human nature could well endure. Myself and some of them were compelled to go with bare feet for several months, reserving our Indian moccasins for extra occasions. We toiled hard and lived on a few greens, and on the thistle and other roots.

The writer has been told by persons who lived through this period that the domestic fowls of the households devoured such quantities of the crickets as to make their eggs quite unpalatable, thus cutting off a minor source of food. Furthermore, the crickets attacked the small grazing lands available for live stock, thus adding another burden to the major one.

Now the nearby Paiute Indians found in these very crickets a pleasant delicacy and ate them in large numbers. But the food-habits of the white man prevented a sensible adaptation to the Indian usage. Differences in culture make differences of tastes.

The Mormons, like all people of primitive culture status, confused natural with supernatural or magical practices. And while they made untiring attempts to combat these pests, they also resorted to prayer and magic for release from the strain and problem. Man confronted with the futility of his own efforts seems to resort to supplication or to magic, or both, to obtain his desires. So, here, entreaties were made for divine intervention to free them from this plague. The following Mormon account gives at once the essential facts of the situation and also the settlers' rationalization of the event:

> They were saved, they believed, by a miracle. . . . In the midst of the work of destruction, when it seemed as if nothing could stay the devastation, great flocks of gulls appeared, filling the air with their white wings and plaintive cries, and settled down upon the half-ruined fields. At first it seemed as if they came but to destroy what the crickets had left. But their real purpose was soon apparent. They came to prey upon the destroyers. All day long they gorged themselves, and when full, disgorged and feasted again, the white gulls upon the black crickets, like hosts of heaven and hell contending, until the pests were vanquished, and the people were saved. The heaven-sent birds then returned to the lake islands whence they came, leaving the grateful people to shed tears of joy at the wonderful and timely deliverance wrought out for them.

Bancroft, in his "History of Utah," reports that later in the same season grasshoppers or the "migratory" locusts (*Melanophus spretus*), did considerable damage to the remaining crops. And the next year the crickets appeared again, although not in such numbers. This, coupled with drought and frosts, made the second year almost as severe as the first. From time to time during the next ten years the pioneers had to combat both crickets and grasshoppers. In 1854 and in 1855 the crops failed due to the grasshoppers. This reduced the group to straitened circumstances and in these years the gulls did "not come to the rescue."

Yet for the year 1848 the "miracle" of the gulls meant survival. Naturally much significance was attached to their visitation. The superstitious pioneers gave thanks to their god for deliverance from threatened disaster. The crisis of famine had been met successfully by what seemed divine intervention. The crops were harvested and though not bounteous were sufficient to see them through the coming winter. The harvest festival which was held is typical of a group-response to this happy solution of a serious crisis. Bancroft writes:

> On the tenth of August, however, the harvest being then gathered, a feast was held in the

bowery (a community structure for religious services), at which the tables were loaded with a variety of viands, vegetables, beef, and bread, butter and cheese, with cakes and pastry. Sheaves of wheat and other grain were hoisted on harvest poles; and [says Parley P. Pratt] there was prayer and thanksgiving, congratulations, songs, speeches, music, dancing, smiling faces, and merry hearts. . . .

The Mormons naturally developed a high reverence for the gull. Songs were sung, poems written, sermons and personal "testimonies" given concerning the supernatural deliverance. The bird became a sacred object to these people. The territorial government which was organized shortly thereafter and which was completely Mormon in composition, passed legislation prohibiting the killing of the gull. The official Mormon historian, Mr. Whitney, gives the following panegyric on the birds:

> Is it strange that among the early acts of Utah's legislators there should be a law making the wanton killing of these birds a punishable offense? Rome once had her sacred geese. Utah would thenceforth have her sacred gulls. Ye statesmen and state-makers of the future! When Utah's sovereign star, dawning above the dark horizon of factional strife, shall take its place in the blue, unclouded zenith of freedom's empyrean, and it is asked by those who would frame her escutcheon, what shall her emblem be? Name not at all the carpet-bag. Place not first the bee-hive, nor the eagle; not yet the miner's pick, the farmer's plow, nor the smoke-stack of the wealth-producing smelter. Give these their places, all, in dexter or in middle, but whatever else the glittering shield contains, reserve for the honor point, as worthy of all praise, the sacred bird that saved the pioneers.

While the Mormon statesmen did not heed Mr. Whitney's suggestion, the gull incident has continued to play a very large part in the folk-lore and history of the state. And as a final culmination to this development, as an artistic rationalization, has come the erection of the "Sea-gull Monument" in Salt Lake City, showing atop a shaft of thirty feet or so a golden ball upon which two gulls are placed. Around the base of this monument are four reliefs portraying the coming of the pioneers into the Great Basin, the planting of crops, the contest with the crickets and, finally, the "miraculous" deliverance by the gulls.

II

So much for the story. What as to its meaning for the study of the rise of a social taboo and a folk-lore?

In the first instance, it must be noted that although this religious body drew most of its fundamentals from such creeds as the Campbellites, the Baptists and from the general Puritan tradition, its concepts were decidedly primitive throughout. The belief in direct, divine revelation was basic as was the belief in a divinely appointed priesthood and in miracle-working. The long history of hardship and persecution had produced an intense loyalty and sense of social solidarity. The pioneer life had thrown these people into a distinctly alien and elemental country with a reduction of life to a direct struggle for existence. It is true that they brought with them the material culture of their contemporary civilization which enabled them to till the soil, put irrigation into effect and to construct a more adequate economic life than the Indians around them had. But as to what may be called non-material or psycho-social culture, especially on the side of religious beliefs and notions of magical power and supernatural influences, they were not greatly advanced over the Middle Ages or the peasant peoples of Europe and Asia. As one must recognize at all times, the state of learning and the manner of life are not a matter of time or place but of cultural level. In regard to interpretations of natural phenomena, the Mormons were much inclined to magical thinking.

While their Protestant background prevented the development of a whole series of rituals and public festivals in

reference to the gulls, certainly a rigid, rather superstitious taboo arose concerning them. Furthermore, the rise of the bird to a position of worship as a totem of the group was incipient but prevented by the existence of other culture patterns of more complex sort drawn from their religious and theological background. Still, we may note, in conclusion, how much of rudimentary reaction and interpretation did remain. We may summarize the following stages in the development of this whole culture complex of the gull:

(1) We have a severe group crisis. The food supply is threatened by the pest of crickets. Group survival is at stake.

(2) There is an inability to cope with the situation by any naturalistic means. In other words, common-sense techniques do not suffice to allay the crisis.

(3) There is a turning to God for help. Actually, of course, with these vigorous people there was a combination of work and prayer. Aggressive Christian peoples facing starvation are not apt to forget the injunction to *faith and works*.

(4) There is some delay in the answer to the first entreaties to God for deliverance. Men of that generation of Mormons have been known to say that this occurred "in order to test the faith of the people"—a very typical rationalization. Thus the crisis continues to grow more and more alarming and this in spite of renewed efforts of their own techniques and of additional piety.

(5) There is a growing despair on the part of the group as they see their crops being destroyed. There is great emotional disturbance consequent to this: fear, sorrow, anticipated grief and hardship. No doubt in some skeptical ones there is slight anger at the delay of God in responding to supplications. Certainly there is rage and an unpleasant feeling of balked effort toward the insects.

(6) The rather sudden appearance of the gulls with some perturbation at first that they might also be bent on destroying that which the crickets had not yet devoured. Thus, increased emotional toning is developed, that is, fear and anger toward the gulls that they might assist in the final consumption of the growing crops and thus complete the horror.

(7) The unexpected, the amazing behavior of the gulls in devouring not the crops but the insects. This not in few cases but in great quantities; their disgorging these, so legend has it, and their curious repetition of eating still more crickets. Here we have the surprise turn or climax of a socio-economic drama in real life. Here we see the operation of what Sumner called the aleatory or luck element in social crises.

(8) The saving of the crops, then, led to giving thanks to God who is credited with sending the gulls, not to the gulls directly, since the religious cast of their minds prevented this more primitive response. There was also the verbal testimony in church gatherings about this "miraculous" solution. There is, in short, the religious thrill of deliverance from evil and a return to good. As Sumner puts it:

> The minds of men always dwell more on bad luck. They accept ordinary prosperity as a matter of course. Misfortunes arrest their attention and remain in their memory. Hence the ills of life are the mode of manifestation of the aleatory element which has most affected life policy . . . Good or ill luck were attributed to superior powers, and were supposed to be due to their pleasure or displeasure at the conduct of men . . . The aleatory element has always been the connecting link between the struggle for existence and religion.

(9) Then came the raising of the gull to a place of religio-economic significance and the placing of a taboo upon its destruction. It becomes a sacred object.

Thus we see illustrated the fundamental nexus of religion and socio-economic life witnessed in all rudimentary societies.

(10) There has come a whole local literature, history and folk-lore about the gulls among these people. Thus a legend has grown up about the crisis and its solution. Curious attributes of insight and intelligence have been given them, often quite contrary to fact.

(11) Recently we have a final culmination in an object of veneration and communal attention, if not direct worship, which serves for the group as a rallying point in recall and contemplation of this miracle. That is, we have a monument to the gulls which is a kind of attenuated, amorphous totem pole, something which in more simple cultures might have played a very distinct rôle in the daily religious life of a people.

III

To mention the wider implications from this curious incident: In the first place one notes the importance of disaster or crisis in producing the taboo and the new folk-lore. No doubt a great many of our taboos and methods of social control arose in critical situations not unlike this one in general features. In the second instance, one must recognize the psychological factors in the situation, such as the arousal of intense emotions, the feelings of balked effort and the tendency to superstitious and magical thought processes when the commonsense means failed. Finally, the direction which the interpretation of this experience took was determined by the previous experience, by what the anthropologist calls the culture patterns, of the group. Thus, the development of real animal worship and the making of the gull into a true totem were probably prevented by the existence in the minds of these people of religious and social ideas of a higher and different order from those current in more primitive peoples.

THE WIDER ASPECTS OF COSMOGONY[1]

By Dr. J. H. JEANS

SECRETARY OF THE ROYAL SOCIETY

INTEREST in scientific cosmogony is a recent, and still a very tender growth. Anthropologists and geologists tell us that man has existed on earth for something like 300,000 years; we must go this far back to meet our ape-like ancestry. Between them and us some 10,000 generations of men have walked the earth, most of whom have probably given some thought, in varying degrees, to the significance of their existence and the plan of the universe.

Of these 10,000 generations of men, the first 9,990 unhesitatingly regarded the earth as the center, and terrestrial life as the central fact, of the universe. As was suited to its majesty and dignity as the abode of man, the earth stood still while the celestial sphere spun round it, covering in the earth much as a telescope-dome covers in the telescope; and this dome was spangled with stars, which had been thoughtfully added so as not to leave the central earth unillumined at night. Ten generations at most have been able to consider the problem of their existence in anything like its proper astronomical perspective.

THE POSITION OF MAN IN THE UNIVERSE

The total age of the earth far exceeds the 300,000 years or so of man's existence. The evidence of geology, and of radio-activity in rocks in particular, shows that it must be something like 2,000 million years, which is several thousand times the age of the human race. Old Mother Earth must regard man as a very recent apparition indeed; he has just appeared to burrow into her, burn her forests, put her waterfalls into pipes, and generally mar the beauty of her features. If he has done so much in the first few moments of his existence, she may well wonder what is in store for her in the long future ages in which he is destined to labor on her surface. For in all probability the life in front of the human race must enormously exceed the short life behind it. A million million years hence, so far as we can foresee, the sun will probably still be much as now, and the earth will be revolving round it much as now. The year will be a little longer, and the climate quite a lot colder, while the rich accumulated stores of coal, oil and forest will have long been burnt up; but there is no reason why our descendants should not still people the earth. Perhaps it may be unable to support so large a population as now, and perhaps fewer will desire to live on it. On the other hand, mankind, being three million times as old as now, may—if the conjecture does not distress our pessimists too much—be three million times as wise.

Looked at on the astronomical time-scale, humanity is at the very beginning of its existence—a new-born babe, with all the unexplored potentialities of babyhood; and until the last few moments its interest has been centered, absolutely and exclusively, on its cradle and feeding-bottle. It has just become conscious of the vast world existing outside itself and its cradle; it is learning to focus its eyes on distant objects, and its awakening brain is beginning to wonder, in a

[1] The Trueman Wood Lecture delivered before the Royal Society of Arts on March 7 and printed in *Nature*.

vague, dreamy way, what they are and what purpose they serve. Its interest in this external world is not much developed yet, so that the main part of its faculties is still engrossed with the cradle and feeding-bottle, but a little corner of its brain is beginning to wonder.

Taking a very gloomy view of the future of the human race, let us suppose that it can only expect to survive for two thousand million years longer, a period about equal to the past age of the earth. Then, regarded as a being destined to live for threescore years and ten, humanity, although it has been born in a house seventy years old, is itself only three days old. But only in the last few minutes has it become conscious that the whole world does not center round its cradle and its trappings, and only in the last few ticks of the clock has any adequate conception of the size of the external world dawned upon it. For our clock does not tick seconds, but years; its minutes are the lives of men. A minute and a half ago the distance of a star was first measured and provided a measuring-rod for the universe. Ten seconds ago Shapley showed how the peculiar stars known as Cepheid variables provide a longer measuring-rod, and taught us to think in distances so great that light takes hundreds of thousands of years to traverse them. With the very last tick of the clock, Hubble, using the same measuring-rod, has found that the most remote objects visible in the biggest telescope on earth are so distant that light, traveling 186,000 miles a second, takes about 140 million years to come from them to us.

Not only is our vision of the universe continually expanding, but also it is expanding at an ever-increasing rate. Is this expansion destined to go on for ever? So far as we can at present see, no; for a general guiding principle, that of generalized relativity, fixes a limit, which we are fast approaching. According to this theory, space can not extend for ever; it has no limit, but is nevertheless finite like the surface of the earth. Without exploring and surveying the whole of the earth's surface, we can make a fair estimate of its total area by measuring its radius, which we can do by measuring its curvature at any one point. In the same way the total volume of space is fixed by a quantity, the curvature of space, which can be determined by measuring the density of distribution of matter in space. Space which contained no matter would go on for ever, but the parts of space we can survey with our telescopes contain enough matter to show that we already see an appreciable fraction of the whole of space. It is as though our baby, watching ships coming from over the horizon, concluded that the earth's surface was curved, and formed a general rough conception of its size by imagining the observed curvature continuing until the earth's surface rounded back on itself.

Exact figures are impossible, but Hubble has calculated that space is not likely to extend to more than about a thousand times as far as the farthest nebula visible in the biggest telescope. Nothing prevents our going on and on in space beyond this distance, but, if we do, we merely come back to ourselves. The possessor of a sufficiently sensitive wireless apparatus may emit signals and pick them up a seventh of a second later after they have traveled round the world. In the same way a not inconceivable increase in the size of our telescopes would take us round the whole of space, and we should see the stars surrounding our sun by light which had traveled round the universe, not of course as they now are, but as they were 100,000 million years ago.

Such considerations make it improbable that the expansion of the universe can continue at its present rate for much longer. Having grasped that the world is round, the infant speedily forms a fair idea of its size. Our particular infant, mankind, has made the great discovery of the existence of the outer world, has formed some conception of its size, and adjusted his ideas, not by a process of slow revelation, but by a brain-flash of the last few seconds. In his mature years and his staid old age he is no doubt destined to make many sensational discoveries, but he can never again live through the immortal moment at which he first grasped the immensity of the outer world. We only live through a few ticks of his clock, and fate might have ordained that they should be anywhere in the three days that the child has already lived, or in the seventy long, and possibly tedious, years yet to come. The wonderful thing is that she has selected for us what is, perhaps, in some ways the most sensational moment of all in the life of our race.

The child sets its newly awakened mind to work to adjust and coordinate a new array of facts. If the world was not made to surround its cradle, what purpose can it serve? If the lights of the great ships in the harbor were not designed to light its nursery at night, what can they possibly be for? And, most interesting problem of all, if the world is such a big affair, can there be other cradles and other babies?

These remarks will have served their purpose if they suggest that what I am rashly trying to set forth here should not be judged as a finished science or the solution of a problem; it is rather the first confused gropings of the infant mind trying to understand the world outside its cradle. And if the impression produced by its first inexperienced glance at the outer world had to be described in a single word, it would probably select the word "immensity."

The Immensity of Space

The immensity of space is measured by the figures already mentioned. Light and wireless signals travel at the same rate because, of course, they are essentially the same thing; and this thing takes a seventh of a second to travel round the world, and probably something like 100,000 million years to travel round the universe. The ratio of these times (2×10^{19}) measures the dimensions of the universe in terms of the familiar dimensions of the world; incidentally, it also measures the expansion of our spatial ideas since Copernicus. The disparity of size is too great to be easily visualized. Suppose the size of our earth represented by a single atom. Then the range of vision of the biggest telescope is about represented by the whole earth, and the size of the whole universe, according to the theory of relativity, is represented by a stack of a thousand million earths.

Scarcely less bewildering than the immense extent of space is the immense amount and variety of matter it contains. The sun, which is a million times as big as the earth and 300,000 times as massive, proves to be something less than a grain of sand on the seashore. It forms one of a family whose number must certainly be counted in thousands of millions; Seares has estimated it at thirty thousand millions. This is not the only family of stars in space. Each of the great spiral and other extragalactic nebulae, is either a family of stars, or consists of stars in the making, or of matter which is destined ultimately to form stars. We can estimate the masses of these great nebulae by gravitational means, and each is found to contain enough matter to make a thousand million suns. This of itself will give some conception of the vast size of these

nebulae, but to tell the whole story, it must be added that their colossal masses are so tenuous that each millionth part of an ounce is, on the average, as big as the Matterhorn. Think of a body which is bigger than the Matterhorn by as much as a thousand million suns is heavier than a millionth part of an ounce, and we have the size of any one of these great nebulae. Any one of the three photographs that I have would have to be enlarged so as to cover the whole of Asia before a body of the size of the earth became visible in it at all, even under the most powerful of microscopes.

Hubble estimates that about two million such nebulae are visible in the great 100-inch telescope at Mount Wilson, and that the whole universe has about a thousand million times the volume of that part of space visible in this telescope. Let us now multiply 1,000 million by 2 million, and the product by 1,000 million. The answer (2×10^{24}) gives some indication of the probable number of stars in the universe; the same number of grains of sand spread over England would make a layer hundreds of yards in depth. Let us reflect that our earth is one millionth part of one such grain of sand, and our mundane affairs, our troubles and our achievements, begin to appear in their correct proportion to the universe as a whole.

While the stars may fairly be compared to grains of sand in number, they differ too much *inter se* for the comparison to be carried further. There is an enormous variety of big and little stars, of bright and faint stars, of red and blue stars, and of hot, hotter and still hotter stars. The faintest of known stars (Wolf 359) emits only a fifty thousandth part of the light of the sun, while the brightest (S. Doradus) emits 300,000 times as much light as the sun. The smallest known star (Van Maanen's star) is about the size of the earth; a million such stars could be packed inside the sun and leave room to spare. The largest known star (Betelgeuse) is so large that 25 million suns could be packed inside it. Their ranges are greater than those between a searchlight and a glowworm, or between balloons and bird-shot.

Yet the stars are essentially similar structures. A normal atom consists of a central nucleus round which a number of electrons revolve like planets round the sun—a miniature solar system, in fact, in which the vacant space far exceeds that occupied by matter. With great heat the electrons begin to break loose and fly off at a tangent. The central temperatures of the stars can be calculated with fair precision, and prove to be so high that most of the electrons must have already broken loose from their atoms. Of recent years, a great deal of labor has been devoted to testing the hypothesis that practically all the electrons have so broken loose, the stripped atoms and electrons flying about in a general hurly-burly like the molecules of a gas. But the hypothesis has proved disappointing, and a much more probable hypothesis is, I think, that the atoms are not stripped quite bare, but that in most stars they retain a few rings of electrons which give the atoms so much size that they jostle one another about like the molecules of a liquid. This hypothesis explains beautifully the otherwise puzzling fact that stars of large mass fall into distinct groups, of what may almost be described as "standardized" sizes. On the "liquid star" hypothesis, these different sizes correspond to the different sizes possible for the stellar atoms, which may have 0, 1, 2, or 3 rings of electrons left, but can not have fractional numbers. The largest stars of all, such as Betelgeuse, have three rings left, while minute stars, such as Van Maanen's star, con-

sist of atoms most of which are stripped quite bare, so that there is almost no limit to the closeness with which they can be packed together. An average handful of the matter of which this star is composed would contain about ten tons.

Thus the observed sizes of the stars proclaim the secret of the structure of the atom. The sizes of the stars are discontinuous because the sizes of atoms broken down to different stages are discontinuous. These discontinuities can be traced in turn to the discontinuities which form the central feature of the new quantum dynamics. Thus the distinguishing characteristic of the laws which govern the most minute processes in Nature is transmitted directly into the large scale phenomena of astronomy and governs the distribution of the huge masses of the stars. The infinitely great is never very far from the infinitely small in science, but it would be hard to find a more sensational illustration of the unity of science than that I have just given.

On this hypothesis, not only do the observed sizes of the stars disclose the general structure of the atom, which is old knowledge, but they also reveal the detailed structure of the particular atoms of which the stars are composed, and this is new knowledge. To be precise, the observed sizes of the stars disclose the atomic weights of the stellar atoms; they indicate that the stellar atoms are probably rather heavier than the heaviest atom, uranium, known on earth. The atoms which reveal their presence in stellar spectra are, of course, atoms of the ordinary terrestrial elements—hydrogen, iron, calcium, and the like. These, being the lightest atoms in the star, must naturally float up to its surface, and, as the earth was originally formed out of the surface of the sun, the earth is necessarily composed of them. But it now appears likely that down in the depths of the stars are other unknown and heavier atoms. We may almost say that it must be so, for no terrestrial atoms, not even radium or uranium, can produce anything like the amount of energy which these stellar atoms are observed to produce.

The Immensity of Time

The immensity of space is paralleled by that of time. We can estimate the ages of stars from the impression that time has made upon them, just as we estimate the age of a tree from the number of subdivisions of its stem, or of rings in its cross section. There are three principal methods of doing this. The orbits of binary stars, which are circular at birth, are gradually knocked out of shape by the forces from passing stars. As we can calculate the rate at which this process occurs, the shape of stars' orbits can be made to reveal their ages. The moving clusters provide a second method. Groups of bright stars such as the Great Bear, the Pleiades, Orion's Belt, are often found to consist of exceptionally massive stars which move in regular orderly formation through a jumble of slighter stars, like a flight of swans through a confused crowd of rooks and starlings. Swans, however, are conscious beings, and continually adjust their flight so as to preserve their formation. The swan-like stars can not do this, so that their orderly formation must in time be broken by the gravitational pull of other stars. When this happens, the lighter stars are naturally knocked out of formation first, while the most massive stars retain their formation longest. This agrees with what is observed, and as we can calculate the time necessary to knock out the lighter stars, we can at once deduce the ages of those which are left in. A third method of investigation rests upon a rather abstruse dynamical theorem, which shows that after a sufficient time the energies of motion of the different

types of stars must tend to equality, the little stars making up for the smallness of their mass by the rapidity of their motion. Seares has shown that the stars near the sun have nearly attained to this ideal state, and as we can calculate the time needed to establish it, we can again deduce the ages of the stars.

It is gratifying and significant that all three lines of investigation lead to the same result: the stars are found to be some millions of millions of years old, perhaps from five to ten millions of millions. We can not state their age with much precision, but it is the general order of magnitude, not the exact figure, that is important.

Stellar Radiation

Year after year, century after century, for millions of millions of years, the sun radiates enough energy from each square inch of its surface to keep a 50 h.p. engine continually in action; still hotter stars may radiate as much as 30,000 h.p. per square inch. If this energy were produced by the combustion of coal, the stars would all be completely burnt out in a few hundreds or thousands of years. Where, then, shall we find a source of energy to last millions of millions of years?

More than twenty years ago I directed attention to the enormous store of energy made available by the annihilation of matter, by positive and negative electrons falling into and annihilating one another, thus setting free the whole of their intrinsic energy as radiation. On this scheme neither energy nor matter had a permanent existence, but only a sort of sum of the two; each was, theoretically at least, convertible into the other. Whether energy is ever transformed into matter we do not know; probably not. But the falling together of electrons and protons forms the obvious mechanism for the transformation of matter into energy, and it now seems practically certain that this is the actual source of the radiation of the stars. A beam of radiation exerts pressure on any surface it falls upon, just as a jet of water does or a blast of air. The reason is that radiation carries mass about with it, and electromagnetic theory tells us the amount of this mass. For example, we can calculate that a searchlight which is radiating 50 horse-power of energy is discharging mass into space with the radiation at the rate of a gramme and a quarter a century; with sufficiently delicate adjustments it might even be possible to observe the recoil of the searchlight. Indeed, the pressure of radiation has actually been measured, although not in this particular way. New mass is of course being continually fed into the searchlight by the electric current.

Each square inch of the sun's surface is in effect a searchlight discharging radiation into space at the rate of 50 horse-power, and so is discharging mass at the rate of a gramme and a quarter a century, and the sun's surface is so large that the sun as a whole is discharging mass into space at the rate of 250 million tons a minute. Now the sun has no source of replenishment. It must have weighed 360,000 million tons more yesterday than to-day, and by to-morrow will weigh 360,000 million tons less. These are not mere speculative statements; they rest on observation, and on generally accepted principles which are directly confirmed by observation.

Allowing for the fact that a more massive star emits more radiation than a less massive one, we can calculate that five or ten million million years ago the sun must have been several times as massive as it is to-day, so that it has already lost most of the mass it had at birth. Of each ton it had at birth only a few hundredweights at most remain to-day. The loss of mass which accompanies radiation is, then, no mere academic hair-

splitting. It is a real astronomical phenomenon, and young stars must be many times as massive as old stars.

There is a certain amount of direct evidence of this change of mass. The radiation of the stars imposes an endlessly recurring capital levy upon their masses, which, as observation shows, is graduated and increases very steeply indeed for the richest stars. The levy makes all the stars poorer, but it also tends to equalize what wealth remains; the older the stars get, the more nearly equal their impoverished masses become. This is a large part of the reason why the stars are nearly equal in mass. The process is most clearly marked in the binary systems, which have been formed by a single star breaking into two. The two component stars of such a system are necessarily of the same age, and it is a matter of observation that the small stars of old systems are nearer to equality of mass than the massive stars of young systems.

Thus observation and theory agree in indicating that the universe is melting away into radiation. Our position is that of polar bears on an iceberg that has broken loose from the icepack surrounding the pole, and is inexorably melting away as the iceberg drifts to warmer latitudes and ultimate extinction.

Five million million years ago the sun had stored up within itself the energy which was destined to provide its light and heat until to-day, and the mass of this energy was many times the present mass of the sun. No means is known by which so much mass could be stored except in the form of electrons and protons. Thus we must suppose that the radiation of the sun through these millions of millions of years has been produced by the annihilation of electrons and protons which existed in it originally, but no longer exist now. These electrons and protons are pure bottled energy; the continuous breakage of these bottles in the sun sets free the radiation which warms and lights our earth, and enough unbroken bottles remain to provide light and heat for millions of millions of years to come.

The amount of energy made available in this way is amazing. The annihilation of a pound of coal a week would produce as much energy as the combustion of the five million tons a week which are mined in the British Isles; an ounce of coal a month would provide locomotive power for all the British railways, while a single drop of oil would take the *Mauretania* across the Atlantic. When we speak of the efficiency of a steam engine as 5 per cent. or so, we regard complete use of the thermal energy of combustion as 100 per cent. efficiency. If we measure the work done against the total intrinsic energy of the fuel, as made available by its complete annihilation, the efficiency is more like 0·00000001 per cent. On this scale the efficiency of the sun and stars is exactly 100·00 per cent.

Modern physical theory shows that the annihilation of an electron must produce a single flash of radiation of wave-length far shorter than any we can produce on earth. As this radiation threads its way through a star, its wave-length is continually increased, or, to use the technical term, the radiation is continually softened. In time it becomes γ-radiation, then hard X-radiation, then soft X-radiation, and finally it emerges from the surface of the star as ordinary light and heat. Consider, however, an electron which is annihilated not inside a star but outside in free space, or in one of the almost transparent nebulae. The short wave-length radiation now undergoes no softening, but travels on until it meets something capable of checking it. Thus all astronomical bodies, including the surface of the earth, ought to be under continual

bombardment by radiation of shorter wave-length, and consequently of greater penetrating powers, than any we can produce on earth.

Many years ago such radiation was detected in the earth's atmosphere by McLennan, Rutherford, and other observers; it has recently been studied in detail by Millikan and others. There is no reason to doubt that it originates just where it ought to, namely, in the great nebulae, and its amount is about what it ought to be, if it is evidence of the whole universe melting away into radiation. The wave-length of the radiation might be expected to reveal the physical process by which it is generated, but the evidence is a bit puzzling. The hardest terrestrial radiation penetrates inches of lead and corresponds to a voltage of hundreds of thousands of volts. The cosmic radiation penetrates about five yards of lead, and the hardest rays are now found to correspond to about 60 million volts. Millikan was at one time inclined to attribute the rays to the combination of four atoms of hydrogen to form an atom of helium, but rays so produced would only be of the hardness corresponding to 30 million volts. There are many ways known to physics of softening radiation, but none of hardening it. Thus we must look for some source more energetic than the synthesis of hydrogen into helium, and I can see no possible stopping-place short of the annihilation of matter. Again, we are not dealing with a minute phenomenon of mere academic interest. In a sense this radiation is the most fundamental physical phenomenon of the whole universe, most regions of space containing more of it than of visible light or heat. Our bodies are traversed by it night and day. Short of going down into a mine or in a submarine we can not escape it, and it is so intense that it breaks up several million atoms in each of our bodies every second. It may be essential to life or it may be killing us.

The Lives of the Stars

The stars are almost certainly born in nebulae of the type of the great extra-galactic nebulae. These nebulae show a great variety of shapes, but a single thread connects them all; they are the shapes of huge masses of gas endowed with different amounts of rotation. So definitely is this the case that when Hubble recently tried to classify the shapes of these nebulae, deliberately and avowedly shutting his eyes to all theoretical considerations, he found that purely observational considerations compelled him to classify them in precisely the sequence I had predicted on theoretical grounds some ten years earlier.

A huge mass of gas which was entirely devoid of rotation would of course assume a strictly spherical shape; rotation would flatten this shape out, just as the earth is flattened by its rotation, until ultimately most of the matter was spread out in a thin disc. Now mathematical theory shows that the thin disc-like structure could not remain a mere featureless mass of gas. Just as the cooling of a cloud of steam causes it to condense into drops of water, so the cooling of a cloud of gas causes it to condense into detached masses. We see the phenomenon in progress in nebular photographs; it is a necessary theoretical consequence of the laws of gases and the law of gravitation.

Now the same theory which predicts that the phenomenon must happen, predicts the scale on which it will happen. We can calculate how much matter will go to the formation of each "drop," and the calculated masses of the drops come out to be just about the same as the masses of the stars. Indeed these drops are stars, and the process just described is that of the birth of stars. Unmistakable stars have been observed in the

outer regions of many of the spiral nebulae. It is naturally not possible to identify every observed spot of light with a star, but some of them show precisely the same peculiar fluctuations of light as characterize a certain class of variable star, the Cepheid variables already mentioned, and these put the identity of these particular spots of light beyond all reasonable doubt.

In these nebulæ, then, we are watching the birth of stars, the transformation of an inchoate mass of gas into an "island universe" of stars. Indeed Hubble found it necessary to end up his classification of nebulae with clouds of stars. At one end of his continuous sequence is a nebula, shaped like a mass of rotating gas, in which not a single star is visible: at the other end a star-cloud in which nothing but stars are visible. Our galactic system of stars is probably the final product of just such a transformation, the Milky Way still recording the position of the equatorial plane of the original nebula.

Stars born in this way may meet with a variety of accidents and these result in different observed astronomical formations. A star may rotate too fast for safety, just as a flywheel may; when this happens it breaks into two, and the two stars so formed revolve endlessly about one another as a binary system. Two stars may run into one another, although this is very rare. A more common occurrence is for two stars to escape running into one another by a narrow shave. When this happens, huge tides are raised on the two stars involved, and these may take the form of long streamers of gas, which ultimately condense into "drops" just as did the gas in the outlying regions of the spiral nebulæ. It seems reasonably certain that the planets were formed in this way.

The birth of the solar system, then, resulted from the close approach of two stars; if a second star had not happened to come close to our sun, there would have been no solar system. It may be thought that with a life of millions of millions of years behind it, one star or another would have been certain to come near enough at some time to tear planets out of the body of our sun. Calculation shows the reverse; even after their long lives of millions of millions of years, only about one star in 100,000 can be surrounded by planets born in this way. A quite unusual accident is necessary to produce planets, and our sun with its family of attendant planets is rather of the nature of an astronomical freak.

In the thousand million stars surrounding our sun there are, at a moderate computation, not more than ten thousand planetary systems, because there has not been time for more than this number to be born. They are of course still coming into existence; calculation suggests a birth-rate of about one per thousand million years. Thus we should have to visit thousands of millions of stars before finding a planetary system of as recent creation as our own, and we should have to visit millions of millions of stars before finding a planet on which civilization, and interest in the outer universe, were as recent a growth as are our own. We are standing at the first flush of the dawn of civilization, and are terribly inexperienced beings.

It may be suggested that the creation of planetary systems is also only beginning, and that in time every star will be surrounded, like our sun, by a family of planets. But no; the stars will have dissolved into radiation or disappeared into darkness before there is time for this to happen. So far as we can judge, our part of the universe has lived the more eventful part of its life already; what we are witnessing is less the rising of the curtain before the play than the burning out of candle-ends on an empty stage on which the drama is already

over. There is not time for many more planets to be born.

Life and the Universe

The planets are the only places we know where life can exist. The stars are too hot; even their atoms are broken up by the intense heat. Nebulæ are in every way unsuitable; even if cool solid bodies exist in them, they would probably be so drenched with highly penetrating radiation as to render life impossible. Life demands a special type of matter, such as does not produce intense light and heat by transforming itself into radiation. We find it only in the surfaces of the stars, which are too hot for life, and in the planets which have been pulled out of these surfaces.

On any scheme of cosmogony, life must be limited to an exceedingly small corner of the universe. To our baby's wonderings whether other cradles and other babies exist, the answer appears to be that there can at best be very few cradles, and there is no conceivable means of knowing whether they are tenanted by babies or not. We look out and see a universe consisting primarily of matter which is transforming itself into radiation, and producing so much heat, light, and highly penetrating radiation as to make life impossible. In rare instances, special accidents may produce bodies such as our earth, formed of a special cool ash which no longer produces radiation, and here life may be possible. But it does not at present look as though Nature had designed the universe primarily for life; the normal star and the normal nebula have nothing to do with life except making it impossible. Life is the end of a chain of by-products; it seems to be the accident, and torrential deluges of life-destroying radiation the essential.

There is a temptation to base wide-reaching inferences on the fact that the universe as a whole is apparently antagonistic to life. Other quite different inferences might be based on the fact of our earth being singularly well-adapted to life. We shall, I think, do well to avoid both. Each oak in a forest produces many thousands of acorns, of which only one succeeds in germinating and becoming an oak. The successful acorn, contemplating myriads of acorns lying crushed, rotten, or dead on the ground, might argue that the forest must be inimical to the growth of oaks, or might reason that nothing but the intervention of a special providence could account for its own success in the face of so many failures. We must beware of both types of hasty inference.

In any case, our three-days-old infant can not be very confident of any interpretation it puts on a universe which it only discovered a minute or two ago. We have said it has seventy years of life before it, but in truth its expectation of life would seem to be nearer to 70,000 years. It may be puzzled, distressed, and often irritated at the apparent meaninglessness and incomprehensibility of the world to which it has suddenly wakened up. But it is still very young; it might travel half the world over before finding another baby as young and inexperienced as itself. It has before it time enough and to spare in which it may understand everything. Sooner or later the pieces of the puzzle must begin to fit together, although it may reasonably be doubted whether the whole picture can ever be comprehensible to one small, and apparently quite insignificant, part of the picture. And ever the old question obtrudes itself as to whether the infant has any means of knowing that it is not dreaming all the time. The picture it sees may be merely a creation of its own mind, in which nothing really exists except itself; the universe which we study with such care may be a dream, and we brain-cells in the mind of the dreamer.

ACTIVITIES IN PLANT PHYSIOLOGY

By Dr. D. T. MacDOUGAL
DESERT BOTANICAL LABORATORY

POSSIBLE activities in plant physiology may be discussed most profitably upon the basis of comprehension of recent movements and present activities in plant dynamics. To gain a perspective of the field it will not be necessary to review the entire subject. The main trend and the direction of the most important developments may be projected or outlined by recalling some of the phases of the subject in which advance has been notable. To do this adequately we need not go farther back than the beginning of the century. Progress in nearly all the branches of science and in invention in the intervening period has been more rapid than in any similar length of time in history.

Researches in biological phenomena characteristic of plants have maintained the general pace. It was at the beginning of this period that DeVries, whose earliest researches date back a quarter of a century previously, made his experimental studies in heredity. That he should have formulated the mutation theory of evolutionary derivation of species by discontinuous variations, the essential feature of which is that of separable, measurable characters, seems to be a logical step from his earlier contribution to the subject of electrolytic dissociation of salts in solutions. DeVries made the mechanism of heredity the subject of experiment to supplement or replace observations on the face of nature; quantitative were substituted for qualitative methods, and the viewpoint taken was physiological rather than anatomical.

So great has been the growth of knowledge in genetics, so numerous its students and so direct its applications in human affairs and in plant and animal industries that it has become a separate academic subject. It is obvious that the original movement has now merged into a stage of diffuse elaboration of details, from which it may emerge only upon the origination of new major conceptions. The perfection of the conception of the gene—its behavior in pure and mixed lines of descent, linkages, crossing over, etc., together—may be taken as in the second stage of movement in this field.

It is now quite on the cards that something definite may result from experimental studies in controlled modifications in heredity. Here I am disposed to believe that my own results from qualitative disturbances obtained by introduction of solutions of electrolytes into ovaries of seed-plants in 1905 constitute the first definite effort in this direction. Tested and pure lines of plants were not available as experimental material nor was it possible at that time to formulate the theoretical conceptions upon which profitable advance might be made in modifying heredity. The recent employment of radiant energy by several skilled investigators has secured results which may form the basis of some positive contributions of great import. It is not yet certain that the genes are affected in such experimentation. In any case it may be safely said that the alterations are to be attributed to destruction of material or to disturbances or rearrangement of the chromosomal mechanism. Whether or not actual constructive action in build-

ing up new characters has been accomplished is yet to be determined.

Other phases of physiology and the contributing workers have been taken over directly by the departments of agricultural or horticultural experiment stations or schools to gain a more speedy and direct application of physiological methods with a consequent loss of contributory power to the general subject. Highly specific results rather than general principles are required.

Contributions in plant physiology find their way into print in a wider variety of journals than any other known subject. Pertinent papers appear in journals of chemistry, biochemistry, physical chemistry, physics, colloids, general physiology, plant physiology, genetics, ecology and in a wide variety of publications of botanical, agricultural, horticultural and forestry science, as well as in the proceedings of societies, academies and institutes. I am unable to name any other field in which the energies of the personnel have been so widely and variously dissipated.

Closely correlated branches are scattered about in a highly inefficient manner in schools, colleges and experiment stations. By reason of this diffusion and dispersion plant physiology in its entirety, including the construction of living matter, and the photosynthetic processes to which the organic world owes its existence, the admitted basis of all agriculture and including within its field the source of nearly all power available to the use of man, is represented by but few more chairs and instructorships in colleges than in 1910. This last count is of little moment, but the deplorable fact remains that the study of plant dynamics as now followed and practiced is clumsy, inefficient and one by which the field of effort tends to become sterilized.

That the content of the subject and that modes of approach have altered at a rapid rate is well illustrated by the fact that a text-book of mine reasonably up to date when published in 1902 is now hopelessly beyond revision as to text and the very table of "constants" would require serious alteration to conform to present-day knowledge. The atom of to-day is not that of 1900 and it is equally certain that the current model will be demoded long before the end of the second quarter of the century.

The content and standards of measurement of such terms as osmosis, plasmolysis, permeability, temperature-effects, growth, tropisms, etc., have changed radically within the laboratory experience of many living workers.

The earlier conception of protoplasm as a foam with solid inclusions was displaced by the idea that it was a two-phase colloid or emulsoid, which idea in turn has given way to the better grounded knowledge that living matter in its more solid portions is a reversible gel with the molecular aggregates arranged in a minute meshwork or fibrillar structure with many free poles. The spaces are filled with watery liquid carrying ions, large or small. The degree of hydration of the jelly depends upon the number of molecules of water held by the free poles of the molecules and by the freely moving ions. Extreme hydration may result in the liquefaction of the jelly and the free movement of particles or aggregates of various sizes in a watery solution as the continuous medium. In some regions of the plant cell, particularly the external part of the plasmatic mass, compounds of the fatty acids, some soluble in water or hydratable and others soluble only in oils, the phospholipins, galactolipins and sterols are present in an irregular layer with strands extending through walls and into the plasma. The arrangement here is one of minute globules with protective layers of proteins, or of phospholipins suspended in a continuous watery medium.

Various combinations are known to exist between carbohydrates and lipoids and between lipoids and proteins.

However complex the system may be, and the above facts simply suggest some of its features, the main feature of protoplasmic material in which the biologist is perennially interested is its hydration. The number of molecules in the shell of water held by the charged particle is in the end the measure of its capacity for action. A whole constellation of agencies affect this feature of living matter. The state of hydration of any plasmatic mass changes unceasingly by the action of the ions or charged particles moving within or through it, and of these the hydrogen ion being the most mobile is the most influential. It is not alone, however, in affecting the colloidal meshwork or the state of suspensions.

We have moved rapidly from the resolution of the minute structure of protoplasm considered as a foam by the use of objective lenses which find their limit at half a sodium wavelength to the employment of the ultramicroscope by which size and movement of particles beyond the range of vision are registered. Cytology must now, to make further gains in its salient, move over onto a basis of the dynamics of colloids. Living matter is like a stream. Depth or cross-section of the bed are features of minor interest unless correlated with the speed of the current, nature and movement of the silt carried, erosive action, source and destination of flow.

Nothing in the foregoing is to be taken as belittling the importance of architecture or the arrangement of the component parts of the cell. On the contrary, there has never been a time when the plan of construction of the living machine has assumed such importance. Throughout the entire range of metabolic activity, in all transformations of energy, in all phenomena depending upon viscosity and surface energy, in all movements of material into and out of the cell, growth, and in operations so wide and large as the movement of water in cohesive columns in stems hundreds of feet in length the state of the colloidal particles, relative positions, form and structure of the walls, and the mechanisms formed by the tissues are of the first importance. Physiological anatomy in its ultimate sense has come into its own.

No matter what field of physiology is considered the experimenter, to attain results of any real value, must proceed upon the basis of the constitution of living material. The conception of a protoplast as a blob of protein no longer suffices to explain cell-activities. The liquid and gelatinous mass also includes mucilages and lipoids. The reactions of the living cell are a resultant of the conjoint action of its constituents, particularly as to exchanges of material with the environment, in which case the composition and condition of the cell-wall is also to be taken into account.

After participating in the work of the Desert Laboratory for more than two decades I wish to restate the conviction that nearly all the more important problems of plant physiology concern the relations of living matter to water in some manner.

The action of the chlorophyll-mills in the conversion of radiant energy and the reduction processes for which they furnish the scene and the accessory materials might well be designated as the most fundamental concrete chain of processes with which biological science has to deal. The approximation of the set of reactions in the green cell, and arrangements by which light acting upon preparations in glass or quartz containers may induce the formation of other substances which may be utilized by living cells carry a series of problems

well worth any expenditure or attention that can be given to them. Encouraging advances have been made in both phases of the subject within the last few years.

It might be profitable to venture a few steps further to point out changing viewpoints as to the nature of stimulations and responses as to the intervention of catalysts in tropistic reactions and the employment of the conception of hormones or messengers transmitting reactions or "trigger effects" to distant cell-masses through living cells, along water-filled conduits and even through sections of dead organs.

We were perforce content until recently to regard growth as one of the unexplained and unexplainable "vital phenomena." Effort is now being made to give mathematical expression of its rate and course. The value of the derived formulae will increase with the inclusion of more of the main variables in the calculations. Like all external manifestations the underlying processes are complicated. If increases in volume are conditional on the formation of a building material as inherent in many theories, and upon substances increasing extensibility of cell walls, actual increases of the molecular mesh of living matter and of the surface attraction of charged particles in osmosis and swelling are also to be taken into account.

Time does not allow a discussion of other important aspects of the subject. I have simply chosen activities in fields with which I have some acquaintance for the purpose of establishing a perspective. I wish further to emphasize the fact that the ends of physiology are not to be attained by restricted methods, standardized equipment or limited range of experimental material. Living material of all types, dead cell-masses, extracted constituents, physical models, such as those with which Pfeffer began his epoch-making researches in osmosis, jellies illustrating some of the properties of living matter, and instruments adapted to the registration of the widest range of behavior and physical properties of protoplasm and of other colloids are all material and tools useful in the workshop of the physiologist.

Specific researches, institutional arrangements and instructional schemes must always be dealt with by those most concerned. But in all activities in the domain of plant physiology, whether research in remeasuring or testing previously accepted generalizations, development of new methods for exploring unknown fields, or in the most specific application of new or little known principles to the nutrition, growth and productivity of crop plants, the soundest and best results will be those attained by the continued use and application of the facts and theoretical conceptions of the mechanism of living matter, as determined chiefly by a study of the dynamics of its colloids, and by increasingly adequate and accurate methods of measurement of impinging forces or environmental agencies.

The art of agriculture, inclusive of breeding, fighting diseases of crop plants, increasing yields of grain and fruits, altering qualities of products, selection and domestication of wild plants, will advance at a rate dependent upon the manner in which practice is continually modified to conform to the latest findings in technical research. Such an adjustment is so well illustrated in medicine, metallurgy and many other fields that it seems unnecessary to discuss the indecision as to this matter which may be encountered in many institutions devoted to industries based on the findings of plant physiology.

WARD'S NATURAL SCIENCE ESTABLISHMENT

By HERMAN L. FAIRCHILD
EMERITUS PROFESSOR, UNIVERSITY OF ROCHESTER

THE passing of this unique institution to the ownership of the University of Rochester is an incident of scientific and educational interest. But the transfer of the quasi-commercial institution to one that is wholly educational is not as surprising and strange as it may appear. The establishment began when its founder, Henry A. Ward, was the professor of natural science in the college; and it was housed on the college campus. Moreover, the enterprise was connected with, or an outgrowth of, the Ward Collections which had been presented to the university. In 1869, after the burning of its building, the establishment was relocated directly across the narrow street (College Avenue), where it has remained.

For over sixty years "Ward's" has been the emporium for natural history material, and with no rival in the wide field. Any fair account of the institution must be a part of the life story of Henry A. Ward, a most remarkable man, "the king of museum builders." The full account of his restless life has not been written. His singular modesty delayed the dictation of his memoirs, and his death by accident, in 1906, destroyed the hope. He was a charming writer and a peerless raconteur. His self-told narrative would have made the most interesting travel-book ever written.

Two racy articles about Ward have been written by William T. Hornaday; one in the *Commercial Travellers Home Magazine*, February, 1896, ten years previous to Ward's death; the other in *The Nation*, July 12, 1906. These have special value because Hornaday is one of the eminent scientific men who had "graduated" from the establishment. The quotations in this writing are from those articles.

As a very young man Ward was a student at Williams College, leaving there to join Agassiz at Cambridge; but doing his geologic work in the Ecole des Mines, in Paris. While collecting and selling fossils in France, England and Germany to pay his expenses in the School of Mines he conceived the plan of making a great and comprehensive educational collection in geologic science. After he had secured examples of the limited material then available in America he spent six years wandering over Europe and part of the orient, quarrying, exchanging and purchasing material.

In the year 1861 his collections in phenomenal geology, paleontology, petrology and mineralogy were exhibited in a large hall in Rochester, to the delight and wonderment of all visitors. Letters from several of the most eminent naturalists of that day assert that the collection as a whole was the finest of its kind in America. And Ward was then only twenty-seven years of age.

But the collection was not salable. It was too large and complete. No institution in America then desired such a great geologic museum. To purchase the material and repay his uncle, Levi Ward, who had financed him, the friends of Ward and the university raised a fund of $20,000 and gave the collections to the college. Its display used the entire top floor of Anderson Hall. A large proportion of the 40,000 labels are in the hand-printing of G. K. Gilbert, who was the senior "alumnus" of Ward's Establishment.

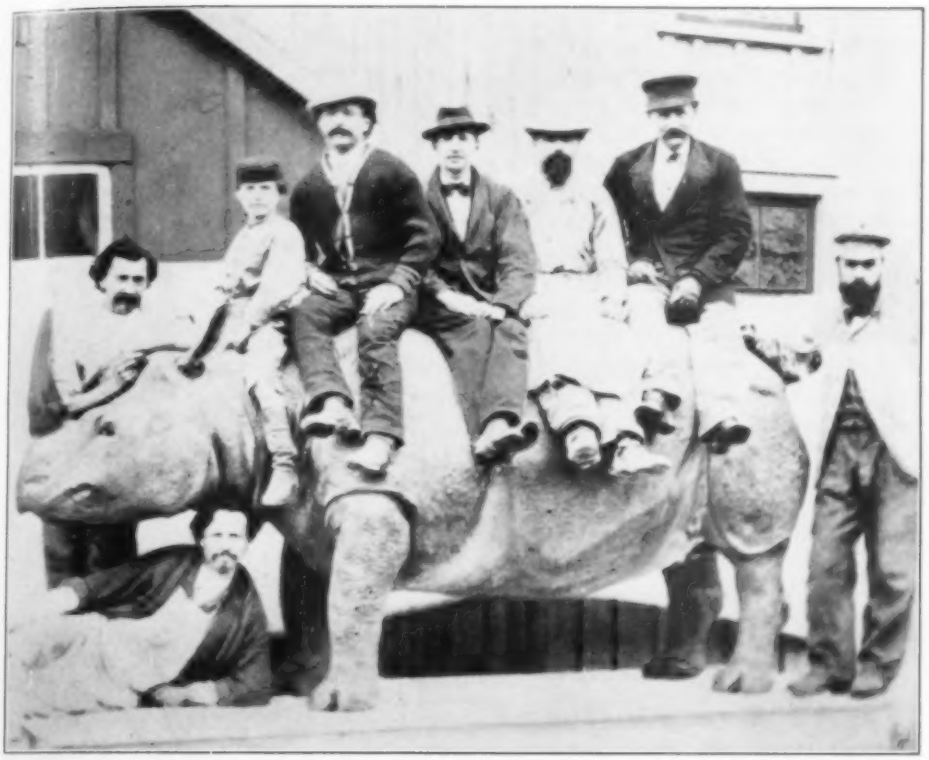


FIG. 1. A GROUP OF WARD'S TAXIDERMISTS, IN 1872. THE BOY IS HENRY L. WARD, AND THE MAN WITH SMOOTH FACE IS FREDERIC A. LUCAS

Twenty years later the museum was removed to Sibley Hall and left unarranged. One of the conditions which drew the writer to Rochester, in 1888, was the opportunity of reclassifying and installing the superb collections.

During Ward's activity in Europe he was able to obtain permission to make plaster molds of the very striking and unique fossils in the great royal museums, which he reproduced for his Rochester museum. Of these Hornaday says: "No sooner were these wonderful casts brought forward than other institutions of learning sought copies from the same molds, and 'Ward's Casts of Celebrated Fossils' was the final result. American teachers and students, to whom the originals were inaccessible, were delighted with them. Illustrated catalogues were issued, the largest of which we used in my alma mater as a text-book."

"Professor Ward's most notable achievement as a scientist and educator was, in my estimation, the colossal task which culminated in the . . . Collection of Casts. . . . Poor indeed is the college or university which does not contain a series. . . . About two hundred sets of them have, I think, found lodgment in the museums and higher institutions of learning in this country."

With accumulation of paleontologic material the plaster imitations are, naturally, in disfavor. But sixty years ago they were a necessary and admirable means of illustration. Even to-day they are desirable for certain unique fossils, like the *Archeopteryx*. And the cast of

a fine fossil is often better than a poor or imperfect original.

Many of the Ward publications, which now number two hundred and ninety-five circulars and forty-three catalogues, have been in demand for use with college classes, especially the ones relating to zoology and paleontology.

Supplying models of type fossils (originals of the invertebrates being largely in the Rochester Museum) was the larger part of the initial work of the establishment. But the business rapidly expanded until it covered all classes of museum and laboratory material in geology and zoology, including taxidermy. Of the latter Hornaday writes: "As early as 1873, when the best of our scientific museums were in their swaddling clothes, and skilled museum preparators were a negligible quantity, Professor Ward assembled at Rochester a corps of the best French, German and American taxidermists, molders and modelers that high wages could procure. In 1876 I was astonished in finding that Rochester afforded better facilities for the study of museum making than Paris, London or Berlin.

"Scores of other men have been trained here in various branches of scientific work and have gone forth to fill positions of responsibility. The Society of American Taxidermists was founded here in 1880 by Professor Ward's taxidermists, and in all its work always received from him hearty sympathy as well as active support and co-operation. It is my firm conviction that no man living has done as much toward

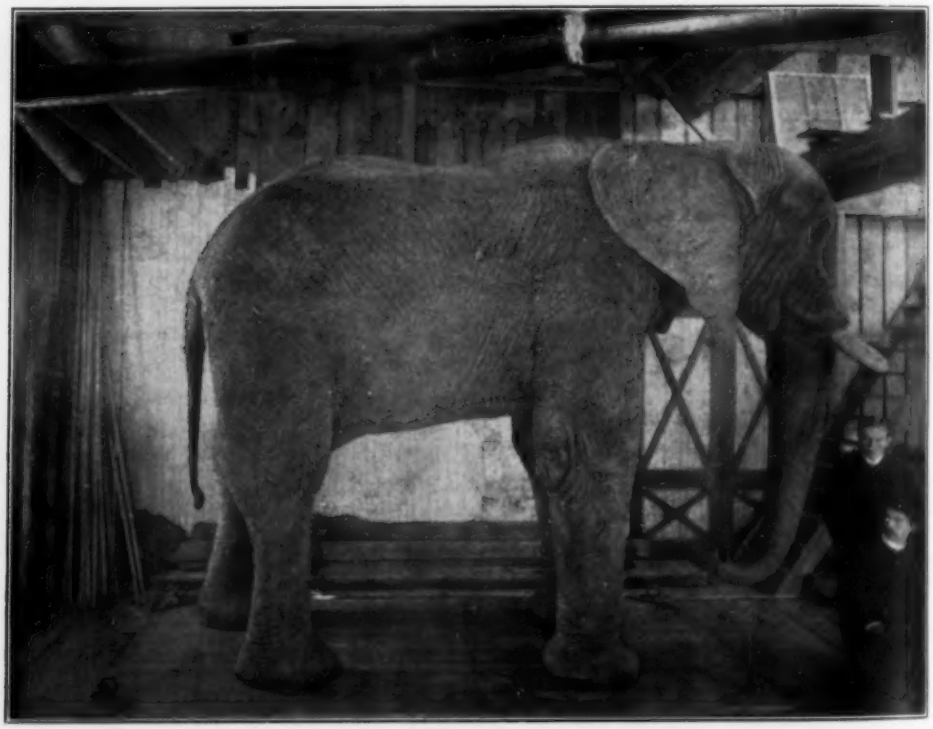


FIG. 2. THE STUFFED SKIN OF JUMBO. AT RIGHT ARE THE TWO YOUNG MEN WHO MOUNTED IT, CARL AKELEY AND WILLIAM T. CRITCHLEY. THE MOUNT IS AT TUFTS COLLEGE; PRESENTED BY P. T. BARNUM. THE SKELETON IS IN THE AMERICAN MUSEUM OF NATURAL HISTORY

the promotion of the art of taxidermy as has been done by Henry A. Ward and the influence created by him."

The photograph, figure 1, is a relic of the early days, taken in 1872. It would be interesting to know where that rhino is to-day.

Carl Akeley went to Ward's in 1883, remaining four years, and associated with William Critchley and William M. Wheeler began his brilliant work. (See the March–April issue of *Natural History*, especially pages 133–146; also Akeley's "In Brightest Africa.")

Ward's was a training school for naturalists. Besides his two sons, Charles H. Ward and Henry L. Ward the following men are counted as among the "alumni." G. K. Gilbert, Frederic A. Lucas, William T. Hornaday, William M. Wheeler, Carl Akeley, Walter B. Barrows, E. W. Staebner, Edwin E. Howell, Charles H. Townsend, George H. Chadwick, Frank C. Baker, and many others.

Ward's establishment was never conducted on a purely commercial basis. "With him (Ward) the idea of educating the masses in the natural sciences by means of object lessons became an absorbing passion. He cared for money only to spend it in wider travel and more collections. And while he found purchasers for great collections as no other man ever did, the huge checks which he received he always joyfully scattered to the ends of the earth in the purchase of more 'museum material.'"

Ward's passion for collecting often overstocked the institution and "broke the market." But serious financial troubles never greatly interfered with the activities of the establishment.

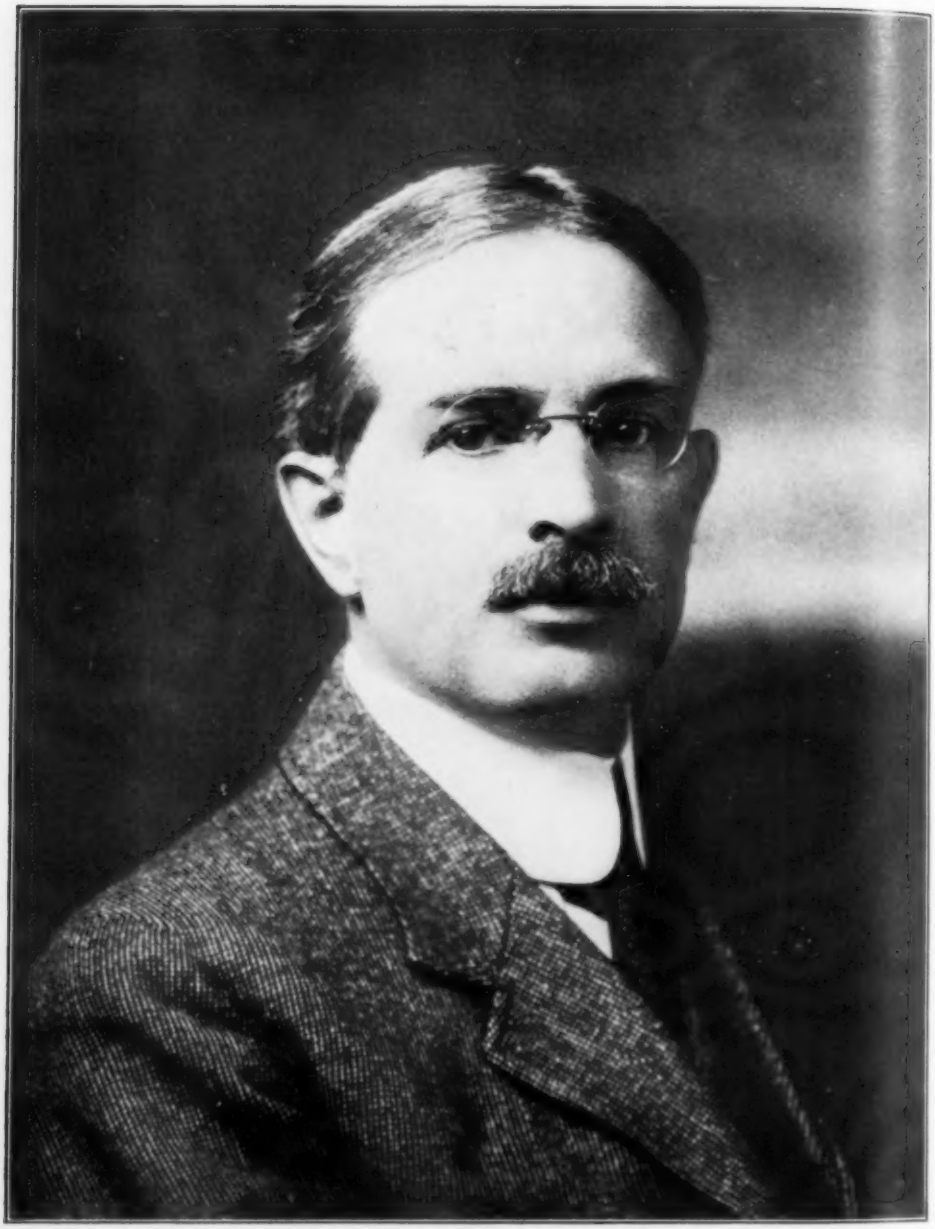
For some years before 1892 the geologic branch of the business was in the name of Ward & Howell; the latter being Edwin E. Howell, who left to found the "Microcosm" in Washington city, devoted chiefly to construction of relief maps.

Professor Ward renewed his world-travel during the later years of his life in carrying out another ambition, to make the most complete collection of meteorites in the world. This is now owned by the Field Columbian Museum, which gave for it over $100,000.

As Professor Ward gradually relinquished control of the establishment it was taken over by his cousin, Frank A. Ward, and his two sons, Hawley Ward and G. Merrit Ward. The sons have now generously donated the institution, its stock, business and good-will, to the University of Rochester in memory of their father.

The new relationship of "Ward's" will be an interesting experiment. It is an example of the widening trend in educational work. The university also possesses the beautiful Eastman Theater, in connection with the Eastman School of Music.

The Wards will continue in the management of the establishment for a few years, while its future operation is being determined. Evidence of its vitality is seen in the recent departure of its consulting mineralogist, George H. English, on a year's trip around the world in search of more material.



THEODORE WILLIAM RICHARDS

THE PROGRESS OF SCIENCE

THEODORE WILLIAM RICHARDS

In the untimely death of Professor Richards, at the age of sixty years, America loses its most distinguished chemist. His father was a leading painter, whose daughter followed the same career. The younger son, Herbert Maule Richards, who died a few weeks ago, was for twenty-five years professor in Barnard College, Columbia University, and contributed largely to the modern development of physiological botany. We have thus a notable example of family distinction and of the relation that exists between science and the fine arts.

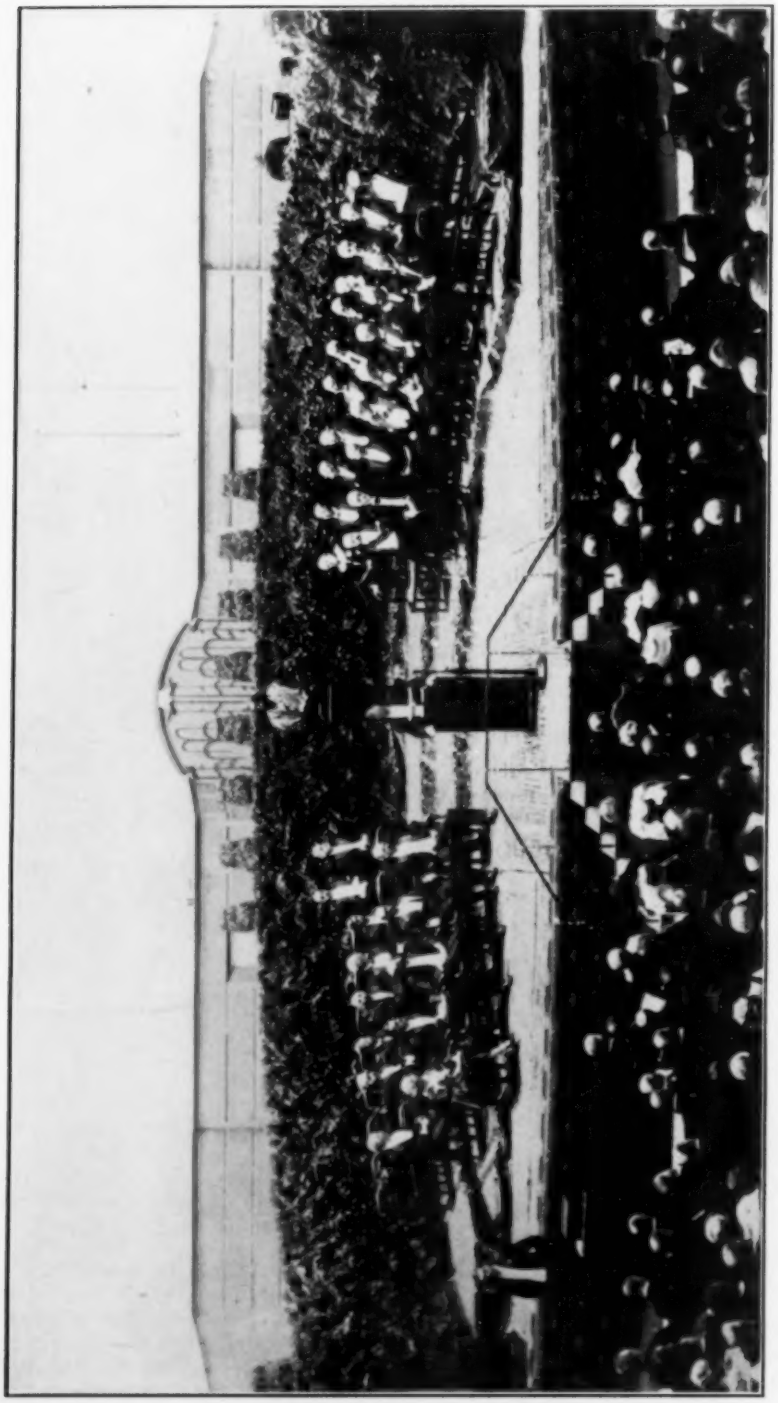
It may be that this journal will be able to print an adequate appreciation of the great contributions to chemistry made by Professor Richards during his tenure of the professorship at Harvard and the directorship of the Wolcott Gibbs Memorial Laboratory. In the meanwhile two tributes may be quoted from the daily press which are of interest in indicating on the one hand the high regard in which Professor Richards is held and on the other the intelligent attention now given to science by the general public.

The New York *Times* says in an editorial article:

> If Lord Kelvin's oft-quoted dictum "Science is measurement" needed any justification, it would be found in the career of Professor Theodore W. Richards, of Harvard; for with him passed one who was a distinguished scientist because he was a skillful, patient and accurate measurer. There is nothing spectacular about determining atomic weights, and Professor Richards played no vivid part in the popular scientific news of the day. Yet his table of atomic weights, which represents the labor of thirty years and constitutes the very basis of chemistry, won for him the Nobel prize in 1914.
>
> Atoms have weight. Lead weighs more than 200 times as much as hydrogen, for example. That fact was ascertained not by weighing an atom all by itself, but by determining the proportions in which atoms combine. Countless such determinations had convinced chemists not only that the atom is indestructible and indivisible but that its weight is constant. Slight irregularities were attributed to errors in experimenting. Richards's restless, inquiring mind was not satisfied. He made careful measurements with copper, silver, sodium. Whether the element came from Alaska or China the result was always the same. Then came the discovery of radioactivity. There was reason to believe that the end products of the spontaneous decomposition of uranium and thorium must be similar to lead if not identical with it. Richards was the very man to settle the question. He made as many as 1,000 fractional distillations of Australian lead nitrate, believed to contain both ordinary and uranium-radium lead. In the end he startled chemists with the announcement that there are at least two kinds of lead (now there are four and possibly six), and that there is a difference between the lead with which we are familiar and that obtained from radioactive ores. Were these different varieties lead elements in the old sense? Hardly. Soddy found it necessary to coin the now generally accepted designation "isotopes." Since then Aston, another Englishman who has built on Richards's work, has received the Nobel prize for his study of isotopes, and the question has been raised whether or not all the elements with which we are familiar may not have broken down from heavier and more complicated structures. So it happens that the influence of Richards is felt throughout the whole field of physical chemistry and that it is scarcely possible to read a technical interpretation of the stars or the transmutation of matter without finding an argument buttressed by a reference to his determinations of atomic weights.

The editor of the New York *Herald-Tribune* writes:

> The death of Theodore Richards removes a great figure of American chemistry, perhaps the greatest. It completes, also, a misfortune to science the first half of which happened only a few weeks ago when Professor Herbert Maule Richards, of Barnard College, a brother three years the junior of Theodore, was taken by death. It is seldom given to two brothers to attain such equal eminence both in their chosen sciences and in the affections of their colleagues as was granted to this unusual pair.
>
> When Theodore Richards died this week American science and the faculty of Harvard lost the most intimate friend of the chemical



THE CEREMONY OF CONFERRING THE NOBEL PRIZES

SCENE IN THE CONCERT HALL AT STOCKHOLM LAST DECEMBER ON THE OCCASION OF THE CONFERRING OF THE NOBEL PRIZES BY KING GUSTAV. THE RECIPIENTS SEATED IN THE FRONT ROW ON THE LEFT SIDE OF THE PLATFORM ARE PROFESSOR J. WAGNER TAUREGG, OF VIENNA, AND PROFESSOR J. FIBIGER, OF COPENHAGEN, TO WHOM THE PRIZES IN MEDICINE FOR THE TWO PAST YEARS WERE GIVEN; PROFESSOR C. T. R. WILSON, OF THE UNIVERSITY OF CAMBRIDGE, AND PROFESSOR A. H. COMPTON, OF THE UNIVERSITY OF CHICAGO, BETWEEN WHOM THE PRIZE IN PHYSICS FOR 1927 WAS DIVIDED, AND SIGNORA GRAZIA DELEDDA, OF ITALY, WHO RECEIVED THE PRIZE IN LITERATURE

atom in the world; a chemist almost unique in his generation for sympathetic understanding of the physicist's views of atoms, as brilliantly exemplified in recent years by the theories of Bohr and the experiments of Thomson, Rutherford and Millikan. An atom has no property more fundamental than its atomic weight and no man in the history of science did more than Theodore Richards to define these weights and to make them certain.

To Herbert Richards the study of living matter proved more attractive than that of atoms. Prominent in that small group of American pioneers who established thirty years ago the new science of the physiology of plants, Herbert Richards brought to his specialty an experimental skill, a sound knowledge and a fine common sense which had won for him when he died unquestioned authority concerning the gases that living plants breathe in and out. His was an authority seldom exercised of his own will, for he was the most modest of men; but upon it his colleagues counted with assurance and delight and they were dismayed to lose it. His lovable personal qualities his friends will long remember with the distress of irreparable loss.

The Richards brothers make an interesting study in heredity. Sons of a father who was the foremost marine painter of his time and a mother distinguished in literature, their ancestry seemed to hold little promise of the cold-blooded exactness which is an essential part of science. It was more imaginative than critical, yet both brothers lived to rank among the sanest and severest critics in their respective fields. The truth is that the imaginative strain is far from negligible in the scientist, for, as Herbert Richards used to declare, insight and foresight are the experimenter's greatest aids. Certainly it was no slavish imitation of his predecessors which led Theodore to conclude before any one else that the heart of an atom lies close to its atomic weight. William T. Richards, the painter father, bequeathed much to the world, for bits of beauty that he conceived still honor the walls of many galleries. But nothing of his was greater, perhaps, than that spark of imagination which did such service for science in the persons of his two sons.

ELECTRONS AND WAVE MOTION

THE scattering of X-rays by a crystal results in the production of strong scattered beams in certain directions, and this fact has always been explained on the hypothesis that X-rays are an electromagnetic wave disturbance of the same sort as radio waves and visible light. The recent experiments of Dr. C. J. Davisson, reported to the American Physical Society, demonstrate that a beam of electrons shows the same characteristic scattering effects as X-rays. The inference seems to be that there is some sort of a wave-motion associated with the motion of a beam of electrons. A few years ago such a statement would have seemed scarcely credible, but we are now prepared to receive it with less scepticism because of recent work in the quantum theory.

The experiments, which were performed jointly with Dr. L. H. Germer at the Bell Telephone Laboratories, showed that the observed wave-length of the electron beam was exactly that which is predicted by the quantum theory as developed by L. de Broglie, E. Schroedinger and others. This wave-length is numerically equal to Planck's constant of action divided by the momentum of the electron. This means that the electron wave-length decreases with increasing speed. For electrons accelerated by 100 volts, the wave-length is roughly equal to the diameter of a single atom.

In these experiments the source of the electrons was a hot filament just as in ordinary radio thermionic tubes. These were accelerated by a positive grid voltage which could be varied at will. The potential used ranged from about 50 to 375 volts. The beam of electrons impinged on a nickel crystal, and some of them were absorbed in it; others were scattered back from the surface of the crystal. Of those that are scattered back some come back without having lost any speed—they have elastic encounters

INDUSTRIAL BULLETIN

OF

Arthur D. Little, Inc.

Established 1886

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THE purpose in issuing the Industrial Bulletins of Arthur D. Little, Inc., is to place before bankers, investors, and industrial executives early and authoritative information bearing upon the present status of industrial development or indicative of its probable trend. The Bulletins are published monthly and mailed free upon request.

TELEPHOTOGRAPHS

YOU are now reading a copy of the first complete periodical that was ever sent over the telephone wires as a telephotograph from which an entire edition was printed and distributed.

A single printed master copy was delivered to the New York office of the American Telephone and Telegraph Company, with instructions to transmit as telephotographs, in their regular commercial manner, the four pages of the sheet to our printer in Boston. A few hours later the printer was preparing electrotypes from these telephotographs, from which he printed this issue of the Bulletin.

This procedure was carried out in order to demonstrate to you the results that are now obtained by this new art in the early stages of its commercial development, and to suggest what may follow when the possibilities of this rapid and accurate method of facsimile transmission are more generally understood and utilized.

ONE NEWSPAPER, EAST AND WEST

In the near future we may expect identical editions of certain newspapers to be published the same day in important cities throughout the country and perhaps the world, thus insuring a centralized editorial policy and permitting various economies. In a recent conversation with the editor of an important daily, he predicted that within a few years through the agency of telephotography identical editions of his paper would appear on the east and west coasts on the same day.

Telephotographs are now being sent between Boston and San Francisco in an over-all time, including delivery, of eight hours, and for a charge of $50.00 per 5 x 7 picture. The rates are intermediate between the other six stations which are strategically located to serve a large part of the country. The actual sending time required is about seven minutes, the photographic work incident to the transmission making the total time from picture to picture about one hour.

When this service was inaugurated the press at once made use of it for the purpose of distributing pictures having immediate national news value, as was recently exemplified in the many pictures which appeared in the press throughout the country on the day following the disaster at the St. Francis dam. In spite of the large number of news pictures regularly sent today the largest users of the telephotograph are the financial houses. They send tabulated figures, balance sheets and statements with a detail, speed and accuracy found in no other method of long distance communication.

RAPID TRANSIT IN STYLES

Other commercial uses are increasing, among which the application to advertising is important. Detailed pictures of the latest Paris models in hats and gowns arrive in this country on the same day that they are released in Paris. Mademoiselle attracts attention in a new bathing costume on the shore of the French Riviera. An American style scout dispatches a photograph by airplane to London and thence by telephotograph to California. That same afternoon Miss Los Angeles christens the recreated costume in the waters of the Pacific.

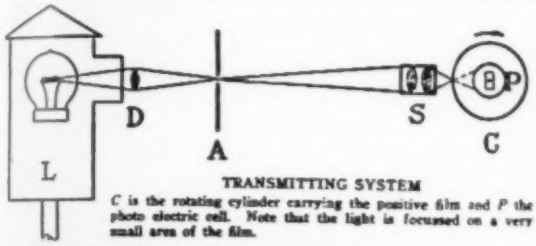
The police send photographs, signatures, detailed descriptions and finger prints to make possible the identification and capture of criminals. Chinese and Japanese characters, hieroglyphics, structural chemical formulae, diagrams indicating new manufacturing processes, and other material totally unsuited for ordinary telegraphic transmission are readily sent, as are X-ray photographs

REPRODUCTION OF A TELEPHOTOGRAPH

THE FIRST TWO PAGES OF THE *Industrial Bulletin* OF ARTHUR D. LITTLE, INC., WHICH WAS TRANSMITTED BY TELEPHOTOGRAPH FROM THE NEW YORK OFFICE OF THE AMERICAN TELEPHONE AND TELEGRAPH COMPANY TO THE PRINTERS IN BOSTON AS DESCRIBED IN THE TEXT. THE WIDTH OF THE PAGE IS REDUCED FROM SEVEN TO FIVE INCHES AND THE TYPOGRAPHY LOSES IN CLEARNESS BY THE REPRODUCTION

which permit a physician at a distance to diagnose an emergency case.

While the value and possibility of telephotography have been recognized for a long time, faithful transmission of a picture has only recently been made possible by combining such new developments as the photoelectric cell, the vacuum tube amplifier, electrical filters and the use of carrier currents. Telephotography is, therefore, not the result of any single invention, but the product of many able minds each working on the perfection of one or more of the several coördinating parts.



TRANSMITTING SYSTEM

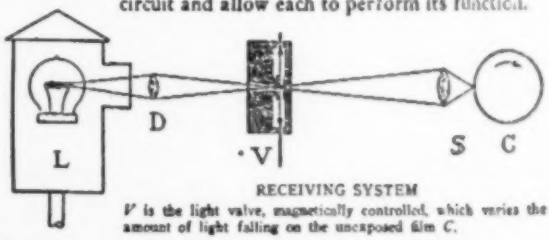
C is the rotating cylinder carrying the positive film and *P* the photo electric cell. Note that the light is focussed on a very small area of the film.

HOW IT IS DONE

In contrast with the technical difficulties which had to be overcome, the principle involved in telephotography is relatively simple. A 5 x 7 positive of the picture to be transmitted is made on a photographic film. This positive is mounted on a frame in the form of a horizontal cylinder which rotates one and one-half revolutions per second and in each revolution moves along the direction of its axis one one-hundredth of an inch. A light beam is sent through the film onto the photoelectric cell at the center of the cylinder. The greater the intensity of the light falling on this cell the greater the intensity of the current which the cell permits to pass. Thus when solid black appears on the positive film no light falls on the cell and the current flowing through the cell is very small; where the film is transparent more light falls on the cell and the amount of current which it passes is greater and in proportion to the intensity of the light which it receives. Thus in a spiral trace the light beam moves slowly over the entire surface of the film and produces a fluctuating current which varies in intensity with the light and shade of the original picture. This electric current is amplified by means of the familiar vacuum tube amplifiers and passed through the telephone circuits to the various receiving points where it is again amplified, and is made to control a light valve. This is a magnetically operated shutter of great sensitiveness, controlling a beam of light. The beam plays upon a cylinder of the same diameter and revolving at the same speed as the cylinder at the transmitting end. On this cylinder is an unexposed photographic film which becomes the negative from which positive prints are made.

Perhaps a clearer mental picture of the mechanism of transmission will be obtained if the reader will place a ruler across the line of capitals forming the title — INDUSTRIAL BULLETIN. It will be seen that each letter is made up of a series of dashes which in themselves form a broken line across the sheet. On this printed page the result is either black or white, the light valve having been either wide open or shut; on a photograph the intermediate grays would be as accurately shown, the valve being partly open.

There are many technical details of importance that must be incorporated in such a system. It is absolutely essential that the two cylinders start and move in synchronism. Impulse motors maintained at constant speed by means of tuning forks, one of which controls the other, are used for the purpose. The starting signal, the tuning fork control signal and the pulsating current carrying the picture are transmitted on carrier currents of different frequencies, in much the same way that the pulsating current from the microphone is impressed on a carrier current for radio broadcasting. Filters at the receiving end similar to radio tuning coils and condensers separate the different frequencies from the single telephone circuit and allow each to perform its function.



RECEIVING SYSTEM

V is the light valve, magnetically controlled, which varies the amount of light falling on the unexposed film *C*.

TRANSMISSION REQUIREMENTS EXACTING

Only the very best telephone lines are satisfactory for these exacting requirements. Even the special lines used for radio chain broadcasting are not entirely suitable for telephotography. Occasional distortion during a radio program

THE CONCLUDING PART OF THE ARTICLE NOT REPRODUCED IN THE PHOTOENGRAVING IS AS FOLLOWS: WOULD NOT GREATLY IMPAIR RECEPTION, BUT A SLIGHT AMOUNT OF DISTORTION DURING THE TRANSMISSION OF A TELEPHOTOGRAPH WOULD RUIN THE PICTURE. WE ANTICIPATE A RAPID GROWTH IN THE USE OF THIS NEW MEANS OF COMMUNICATION, AND BELIEVE THAT MANY EXECUTIVES, BY WHOM THE DEVELOPMENT IS NOW REGARDED AS LITTLE MORE THAN AN INTERESTING EXPERIMENT, WILL SOON BE USING IT REGULARLY IN THE CONDUCT OF THEIR BUSINESS

with the crystal like the impact of a billiard ball on a cushion. A little collecting device was arranged so that it could be moved to various positions in front of the crystal to find how many electrons were scattered in the various directions without loss of speed. The entire arrangement was enclosed in a large glass tube in which was maintained the best vacuum attainable with modern technique.

With this arrangement the number of electrons scattered in different directions was found to depend on the direction in the same way as does the scattering of X-rays by a crystal.

According to Dr. Davisson the situation confronting physicists with regard to electrons is now something like the dilemma confronting the theory of light. For many years all the facts concerning light could be explained by assuming it to be simply a wave motion. Then the quantum theory, in the hands of Planck, Einstein and A. H. Compton, showed that radiation had also to be regarded as having something corpuscular about it. Similarly, for many years electrons were believed to be simply corpuscles of negative electricity. But now recent developments in quantum theory, confirmed by these experiments, show that there is something wave-like about them.

The reconciliation of the apparently conflicting wave and corpuscular viewpoints, both in regard to light and in regard to electrons, is one of the most important problems for theoretical physics.

CASTING OF THE OPTICAL DISK

THE OPTICAL DISK

CASTING OF AN OPTICAL GLASS DISK

THE closing act in an interesting scientific drama that has lasted more than eight months has been staged at the Bureau of Standards, Department of Commerce, with the uncovering of the furnace containing a great disk of optical glass, 70 inches in diameter, 11 inches thick and weighing about 3,500 pounds. When the cover was removed in the presence of a small but distinguished group of scientific experts the glass was found to be practically perfect, and the long period of suspense for those responsible for its production was over. The successful consummation of this work has resulted from the cooperative efforts of several men within and outside the bureau, particular credit being due Mr. J. Walter Drake, former assistant secretary of commerce, Dr. S. W. Stratton, president of the Massachusetts Institute of Technology, Professor C. C. Crump, of Ohio Wesleyan University, and Mr. P. H. Bates, Dr. A. Q. Tool and Mr. A. N. Finn, of the Bureau of Standards.

The disk will be used as a great concave mirror for the new reflecting telescope of the Perkins Observatory at Ohio Wesleyan University, Delaware.

The money with which to establish this observatory was left to the university by Professor Hiram Mills Perkins, of Ohio Wesleyan. It was his desire to establish an observatory of the first rank at the university and that the entire equipment be of American manufacture. It is significant that Professor Perkins had no desire for the observatory to bear his name, his sole wish being, as he expressed it, to enable the students of Ohio Wesleyan and men everywhere to "love God and serve Him more acceptably."

Nevertheless, after his death in 1924, his name was given to the new observatory, work on which had already been in progress for two years.

There was only one real obstacle to delay ultimate achievement—large disks of optical glass of the size required had never been made in this country and only twice abroad. Those that have been successfully completed are said to be imperfect, and although imperfections in the glass are not so important in a reflecting telescope as in a refractor, nevertheless it is always desirable to have glass as nearly perfect as possible.

After four unsuccessful attempts to obtain a disk of the size required, a unique method was developed by Mr. A. N. Finn in charge of the Bureau's glass section: 1,000 pounds of cullet (broken glass of the same composition as the glass to be made) and 4,600 pounds of sand and chemicals were melted in a single large pot in a gas-fired furnace. The molten glass was stirred by hand for six hours and at the proper time on May 7, 1927, the pot was tapped. The molten glass was flowed into a mold of the required size which was specially designed for this purpose. This mold was at the same time a carefully insulated annealing furnace, provided with electrical heating elements by means of which the temperature could be adjusted and controlled to within a degree.

The temperature of the glass when poured was about 2,400° F. For one week the temperature was slowly lowered until it reached 1,112° F. The glass was held at this point for about four days to allow the temperature of the glass and furnace to become uniform throughout. At 1,112° F. this particular kind of glass (boro-silicate crown) is quite rigid and yet sufficiently viscous to yield to cooling stresses without danger of cracking.

Beginning on May 18, the glass was allowed to cool slowly at an average rate of 4½° F. per day till 860° F. was reached. It was then annealed at this temperature for six weeks during which time no variation greater than 2° F. was permitted. Final cooling was started on August 30 and room temperature was attained on January 16. The cover was finally removed on January 21 and the job was done!

During all these months there was no assurance as to what would be found in the annealing furnace when the final "unveiling" took place, because the slightest bit of foreign matter in the glass might start radial cracks which would split the glass into fragments. Too sudden changes in temperature would be equally serious. Mr. Finn and his assistants can now take pride in the fact that the bureau has accomplished a unique and successful piece of work.

Dr. George K. Burgess, director of the bureau, points out that the experience gained for the scientific staff will be of great advantage to the bureau and to any American glass makers who may wish to profit by the results, because all the information obtained is ultimately available to the American public.

The next step toward completion of this reflector is to drill a hole at its optical axis. Although the majority of opticians would refuse to grind a hole in a piece of glass so large as this, except at the owner's risk, on account of the possibility of breaking it, the experts at the Bureau of Standards feel so confident that this can be done without any danger that they will do it at their own risk.

After this the disk will be sent to an optician to be ground, polished and "figured" on one surface until it becomes parabolic. Such a surface has the property of reflecting parallel rays of light to a focus. It is the curve used in automobile headlight reflectors, only in the case of a telescope mirror the curve is so slight that it is hardly noticeable.

With the completion of this disk, Professor Perkins' dream of an all-American telescope will soon be realized.